ERGONOMICS

HUMAN FACTORS IN WORK, MACHINE CONTROL AND EQUIPMENT DESIGN

A Taylor and Francis International Journal

The Official Publication of the Ergonomics Research Society

Volume 2 Number 4

August 1959

ALERE FLAMMAM.

Printed and Published by

TAYLOR & FRANCIS LTD.

RED LION COURT, FLEET STREET, LONDON, E.C.4

ERGONOMICS

Human Factors in Work, Machine Control and Equipment Design

Price 25s. 0d. per part
Subscription price per volume £4 15s. 0d. post free, payable in advance

Agents for U.S.A. and Canada
Academic Press Inc., 111 Fifth Avenue, New York 3, N.Y., U.S.A.
$3.50 per part. $13.30 per volume.

ATTENTION AND DISTRACTION IN THE LIGHTING OF WORK-PLACES

By R. G. Hopkinson and J. Longmore

Department of Scientific and Industrial Research, Building Research Station, Garston, Watford, Hertfordshire

General lighting with a uniform level of illumination over the working plane was introduced and adopted in the inter-war period. Before this, local lighting over the work itself had been customary. It was found, however, that general lighting was not always satisfactory for work which demanded high degrees of visual skill and attention, and in many cases a return to local lighting, together with some general lighting, was favoured.

It is generally accepted that the attention is held by objects which contrast strongly with their environment, either by their brightness, colour, texture or form. Equally the attention can be distracted by a bright or highly coloured object in the field of view a little away from the object of regard.

Experiments have been made in 'human phototropism', employing apparatus which enabled a simultaneous cine-photographic record to be made of the visual scene together with the eye movements of an unsuspecting observer viewing the scene. A count of the number and duration of these eye movements revealed that sharp, intensely bright points of light distracted the attention in a series of jerky eye movements, whereas less bright but larger areas caused more eye movements of longer duration.

Different behaviour patterns of different observers were noticed, two rather distinct groups being recognized which bear many striking similarities to the 'postural-clue' and the 'visual-clue' personality groups recognized by Witkin (1950).

Some applications of the results to the lighting of work-places are suggested. The results argue in favour of preferential lighting of the work, possibly by local lighting.

§ 1. Introduction

This paper describes studies concerned with what seems to be a natural tendency to turn towards the light, or as it is called 'phototropism', and its importance in the design of lighting for work-places. The tendency is well recognized but does not appear to have been investigated quantitatively. Relatively little has been written in the psychological literature about the effect of light in governing the attention, although the subject of attention generally has been studied (see Woodworth and Schlosberg 1954). The literature of painting is more rewarding, but naturally contains little of quantitative value to the engineer.

It is now beginning to be realized that general lighting is not the solution to many important visual problems. When light was expensive, local lighting on the work only was customary. But as soon as light became cheaper, or management was prepared to spend more money on it, there was a swing to general lighting and this is still the fashion. However, the frequency of complaints from people who have to work entirely by general lighting has raised doubt in many minds and it has often happened that in jobs that demand a high degree of visual skill and attention a return to local lighting has been forced by those complaints. A complete return to pre-war practice is, however, rarely made. It is advocated that there must be, in addition to the local lighting, a moderate level of general lighting as well.

Figure 1. Drawing board lit by local light alone. The eyes are attracted to the work and there are no visual distractions.

Figure 2. Modern drawing office with general lighting alone. The ceiling acts as a strong distraction to the eyes to look up from the work.

Figures 1 and 2 illustrate the extremes of the two types of lighting. Figure 1 shows a drawing-board illuminated by a local light alone, as was once customary. There is a high level of illumination (about 100 lumens/sq. ft.) on the work, but the surroundings are in darkness. There is an overwhelming attraction of the eyes by the bright patch, and it is difficult to draw the eyes away from the work. Figure 2, on the other hand, shows a modern drawing-office with general lighting alone. There is rather less light on the work (about 50 lumens/sq. ft) and the ceiling is much brighter. The ceiling consequently acts as a strong distraction to the eyes to look up from the work.

It is also appreciated nowadays much more than formerly that good lighting demands not only the provision of sufficient light to enable work to be done efficiently and in comfort, but also that the distribution of light in the visual field should make the work the natural focus of attention. Dogmatic statements have been made in the past that the attention is commanded by bright or colourful objects in the field of view, without specifying how bright and how colourful these should be.

The present work was designed to supply answers to these questions, but has so far succeeded only partially. In fact, like many first attempts of this kind, it has raised almost as many problems as it set out to solve. This paper is therefore a record of work done, rather than a statement of definite conclusions of engineering value.

The experiments were designed to enable an approximately uniform visual field to be disrupted by the insertion of (*a*) visual tasks, and (*b*) sources of distraction. The latter were introduced into the field of view in different positions and could be given different characteristics of brightness, size and colour. It was intended that the results should relate these parameters to the degree of distraction, or to the degree of holding of the attention in such a way that the data could be used in the engineering of a lighting environment.

§ 2. Experimental Arrangement

An ideal uniform visual field could not be obtained under the conditions in which the work had to be done, because laboratory space could not be set aside for this experiment alone. A near approach to ideal conditions was, however, made. Large white painted screens illuminated by hidden lamps constituted the greater part of the visual field (see Fig. 3), although roof-trusses and rafters above and patterned linoleum below provided unwanted non-uniformities. The observer sat on a chair at a distance of 10 ft from a large white screen about 8 ft $\times$ 6 ft. In the middle of this screen at the observer's eye level a visual task could be placed. For most of the experiment a Landolt ring chart was used, 10 in. square and consisting of 48 black rings in rows of seven, each ring 1·5 cm in diameter with a gap of 4 mm (see Fig. 4). As there were eight directions in which the gap could occur, and the chart could be rotated through four positions, many sets of observations could be made with one chart. In the centre of the chart, and also in the centre of the observer's field of view, was a small aperture of about 1 in. diameter. This aperture always appeared black. It could be closed by a black shutter, or if the shutter was removed, it was carefully screened so that it would still appear black to the observer. The aperture acted as an observing hole through which the

experimenter could either observe the movements of the subject's eyes during the course of the experiment, or record them by means of a cinematograph camera.

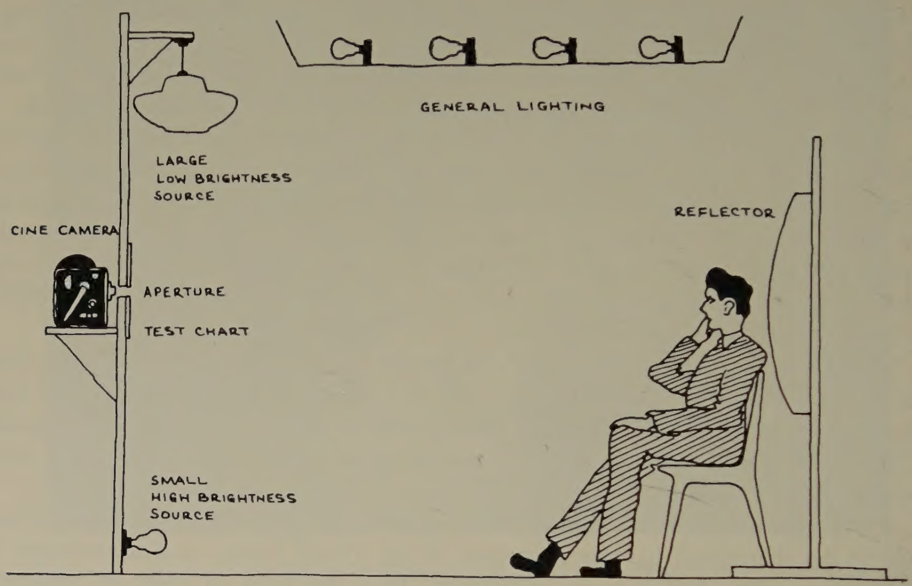


Figure 3. Diagram of the apparatus.

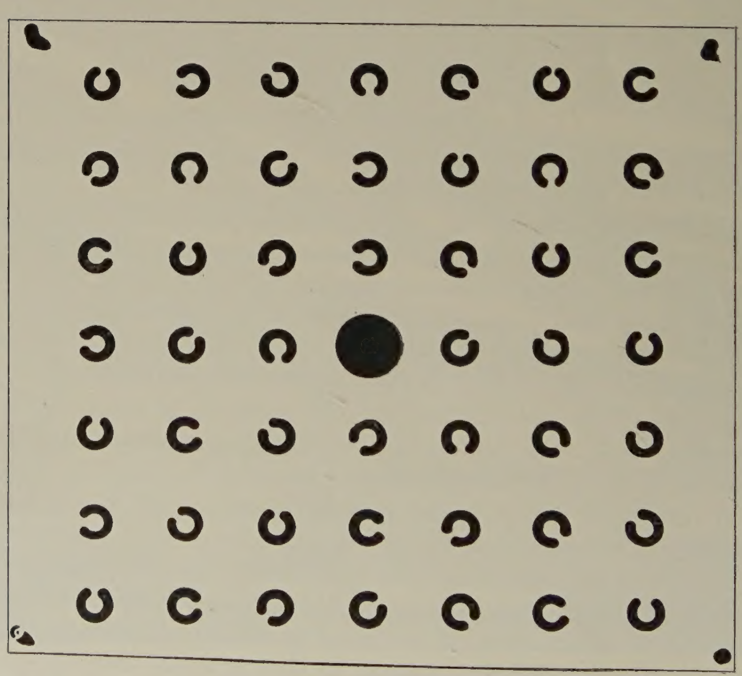


Figure 4. The Landolt ring chart used as a visual task.

It was most important that the subjects should be completely unaware of the purpose of the experiment and also of the fact that they were being observed or that their eye movements were being recorded. If the subjects had been aware that the movements of their eyes were of interest to the experimenter, they could not possibly have acted normally. It was therefore necessary to practise a deception to enable the experiment to succeed.

The subjects were told that the purpose of the experiment was to determine the accuracy with which they could read the Landolt chart both in the presence of and without various distracting sources, and they made their observations in good faith on this basis.

The focal length of the lens of the cinematograph recording camera was chosen so as to include on the frame not only the observer's head but also two convex cylindrical reflectors placed on either side and slightly behind his head. These reflectors consisted of sheets of clear Perspex (2 ft × 1 ft) mounted in black painted boxes and curved to bring the images of the various extraneous light-sources within the field of view of the camera. In this way not only were the observer's eye movements recorded but also the positions of the light-sources giving rise to these movements. Figure 5 is a typical frame from the film record. A small plane reflector could be placed centrally above the observer's head to provide an image of the visual task.

Figure 5. Typical frame from the cinematograph record.

Six light-sources were spaced around the visual task chart approximately 2 ft on either side, two sources being at eye level, two sources 3 ft above and two sources 3 ft below (i.e. displaced 10° horizontally and 20° diagonally from the centre of the visual chart). These sources could be changed in

both size and brightness. The chart itself was illuminated by a masked beam from a projector to give a luminance on the chart which could be varied up to 100 ft lamberts. The luminance of the rest of the visual field could also be varied over a wide range.

2.1. *Experimental Procedure*

The subject was introduced to the experiment and asked to sit down on the observing chair. He was free to assume a comfortable position in the chair without being constrained in any way such as by head rests. The experimenter told him that it was desired to examine his visual acuity under various lighting conditions. These would include a variation of the brightness of the chart, which he would be asked to read. He was told also that various glare sources would be introduced and the effects of these on his ability to read would be investigated. He was asked to treat the test chart as an ordinary reading task and to read it at his normal reading speed, counting up the number of rings which had their gap in a given direction and calling out the answer as soon as he had done this. The observer was told that accuracy and speed were both being recorded and it was stressed that he should not go back over the chart to check his results. If, however, he ignored this instruction it was possible to tell when analysing the film record whether he was actually re-reading the chart or merely gazing at it.

He was told that when he had finished this task he could relax until the results had been worked out and the next task was ready. In fact, close observations of eye movement were made not only while the task was being undertaken, but also during this period of relaxation.

It was explained that the experimenter would be on hand in a nearby recording room and could be summoned if there was any difficulty. Apart from this, however, the subject was asked to make his judgments entirely on his own. The experimenter could then retire out of sight behind the screen either to observe the subject or to operate the camera and make other adjustments to the apparatus.

The procedure for each set of observations was as follows: the experimenter, after telling the observer the orientation of the Landolt gap which he was required to count, switched on the camera. The time taken to read the chart was generally of the order of 10–20 sec and the total running time of the clockwork motor in the camera was approximately $1\frac{1}{2}$ min at eight frames per second. The observer called out the count when he had completed it, the movement of his lips gave a clear record on the film when he had stopped reading and relaxed to await the next task. He was allowed to relax for the remainder of the camera run. The observer was then asked to count the rings for another direction of the gap. Meanwhile the camera was rewound. The shutter behind the aperture in the test chart was closed when the camera was not being used. Three recordings were made for each observer on each occasion out of a total of six or eight counts.

To complete the deception the camera was sometimes removed completely and a light source of relatively low luminance was exposed to the observer through the aperture in the test chart. The observers accepted that this was the reason for having the central aperture.

Some difficulty was experienced with the camera noise. This was partly overcome by playing, during the experiment, a loud recording of miscellaneous noise.

§ 3. Results

3.1. *Preliminary Analysis*

It was clear as soon as the first films were projected that the analysis of the results would involve great difficulties. The behaviour of the observers under the experimental conditions was exceedingly complex. Personality factors tended to dominate the behaviour pattern and mask the phototropic effect. These factors cannot be discussed here. They are, however, important and they were discussed in detail with Professor C. H. Graham at Columbia University, who pointed out that the findings did in fact link up with those reported by Witkin (1950) in his studies of spatial orientation. Briefly, it has been found that observers tend to group themselves into two categories, the one which relaxes more or less completely after the visual task and gives phototropic responses which can be treated quantitatively, and the other which hardly relaxes at all after the task and gives such a confused behaviour pattern that the phototropic responses cannot be analysed systematically. Most of the conclusions which have been drawn from the work so far rest on the observations of the first category of subjects.

The analysis of the cinematograph recordings was made in two ways, one subjective and the other objective. For the subjective observations the films were projected first at normal speed (i.e. at the same speed as the camera) and then very slowly so that the eye movements of the subjects both in the presence of ‘ distracting ’ sources and without them could be observed. These subjective observations showed that:

(*a*) attention remained on the work more effectively if it was locally lit than if it was seen only in general illumination,

(*b*) a light source in the field of view tended to distract attention from the work,

(*c*) the gaze was fixed more readily on a large source of low luminance than on a small source of high luminance,

(*d*) the eye movements in the presence of a large source of low luminance consisted of a series of relatively slow traverses towards the source where the gaze was held for many seconds at a time.

(*e*) the eye movements in the presence of a small source of high luminance consisted of a series of jerky darts towards the source and away again, the gaze never being fixed for more than a fraction of a second at a time. The eyes were sometimes moved only part of the way towards the source and jerked away again, presumably when it was realized that the source was uncomfortably bright.

The complete objective analysis of the cinematograph recordings proved to be too formidable a task for the available staff. An attempt was made, but to date only a small proportion of the data has been treated in this way.

A series of five electrical counters were set up. The rate of counting was synchronized with the film projector so that the speed of counting and projection could be varied. Three of the counters were arranged to run continuously

when switched into circuit and gave one count for every two frames on the film, i.e. four counts per second at the camera speed of eight frames per second.

The first counter was switched on when it was seen from the film that the relevant observing period had begun; for example, motion of the observer's lips on the projected film indicated that the observer had completed the visual task and called out the number of rings he had counted on the chart. This counter was switched off at the end of the observation, thus giving the total time of the observing period. The other counters were connected in pairs to the switch keys so that when a key was depressed one counter made a single count and the other ran continuously until the key was released. Thus the number of occasions of looking in a particular direction was recorded and the total duration of time of looking in that direction. Hence the average time of each glance could be found.

For the analysis of the experiment now to be described it was considered sufficient to obtain the total time of the observation and the number of occasions and total time of looking in the direction of (*a*) the visual task, and (*b*) the distracting light source. Another counting device has since been developed which enables the duration of each glance to be recorded.

3.2. *Detailed Results of a Typical Experiment*

Cinematograph recordings were made of the eye movements of 19 observers. After many preliminary trials eight subjects were selected to make observations under three sets of conditions:

(1) A general illumination of 8 ft-L. was supplemented by a large, low-brightness distracting source of 380 ft-L. in the upper right-hand position, 20° from the centre of the visual field. The illumination of the chart was raised from the general level of 8 ft-L. to 110 ft-L. by means of the screened projector already mentioned.

(2) The projector was on, but the distracting source was not.

(3) The distracting source was on but the projector was not, leaving the chart illuminated at 8 ft-L.

The results of the film analysis are shown in Table 1. They indicate that the effect of the illuminated distracting source was to reduce the amount of

Table 1. Analysis of film record of eye movements of eight observers during relaxation period after completing a visual task

	Condition (1) Distracting source on. Chart illuminated	Condition (2) Distracting source off. Chart illuminated	Condition (3) Distracting source on. Chart not illuminated
Total observing time (in minutes and seconds)	10 min 26 sec	9 min 53 sec	8 min 7 sec
Glances at distracting source			
Number of glances	9	6	12
Total time spent looking at distracting source (in seconds)	6	6	9
Average time per glance (in seconds)	0·67	1·0	0·75
Glances at test chart			
Number of glances	53	54	59
Total time spent looking at chart (in seconds)	246	271	197
Average time per glance (in seconds)	4·65	5·01	3·32

time spent looking at the central chart, although the number of glances at the chart was hardly changed; ('glances' is hardly the correct expression, since much of the relaxing time was spent looking at the chart). When the chart received only the general room illumination instead of the selective 150 lumens per sq. ft, the effect of the illuminated distracting source was more marked. More glances were made at the source when it was illuminated, especially when the chart received only the general room lighting.

All eight observers looked at the chart, whether illuminated or not, for a time equal to almost half the period of relaxation during which observations of eye movements were made. The average time of each glance was about 5 sec when the chart was illuminated and 3 sec when it was not. Only some of the observers looked at the source, four and five respectively out of the eight looked at it under conditions (1) and (3) when it was on, and three under condition (2) when it was off, and they did so for only a short time in each case. The average time of each glance was between half and one second.

3.3. *Analysis of Further Results*

An objective analysis of other lengths of film was made to supplement the early subjective analysis. Seventy-nine film records were examined and although these do not constitute the total data they enable conclusions to be reached on the relative phototropic effects of distracting sources of small area and high brightness or large area and low brightness.

Three conditions were examined having in the field of view:

1. Small source of 30 000 ft-L.
2. Large source of 380 ft-L.
3. Both small source and large source.

The results are shown in histogram form in Fig. 6. The number of glances at the source is plotted against the duration of each glance (on a log scale). It can be seen that the glances at the large source are of longer duration than those at the small source. The medians are shown in Table 2.

When the small source was seen alone 24 per cent of the glances were of only one-quarter second or less. (One-quarter second is the shortest interval that can be obtained with the present method of analysis, so that very short glances are recorded as falling in this category.) When the sources were seen together 12 per cent of the glances at the small source were of one-quarter second or less. However all the glances at the large source under both conditions were longer than one-quarter second. The large source thus occasioned a greater number of glances of longer duration than the small source both when the sources were seen separately and when they were seen at the same time. As can be seen from Table 2, the time spent looking at the large source was 3·26 times greater than that for the small source when seen separately and 4·02 times when seen together.

These differences in the eye-movement patterns are more evident on inspection of the film records than the tables or histogram data can demonstrate. For example, many of the glances at the high brightness source were followed by a quick blink or contraction of the frontalis muscles and then by a quick turning away, suggesting that the gaze was attracted by the light source, but

repelled by the sensation of glare which then resulted. The glances at the lower brightness source were slower and the return movement was also unhurried.

The fact that it was possible for the experimenter to make an analysis of the eye movement with the aid of the counter when projecting the film at the camera speed suggests that the cinematograph recording might be dispensed with, except for record or demonstration purposes, and the analysis made directly by the experimenter at the time the experiment is being conducted. This would have a number of advantages in that the duration of the experiment need not be limited by the time which the camera can be left running, but

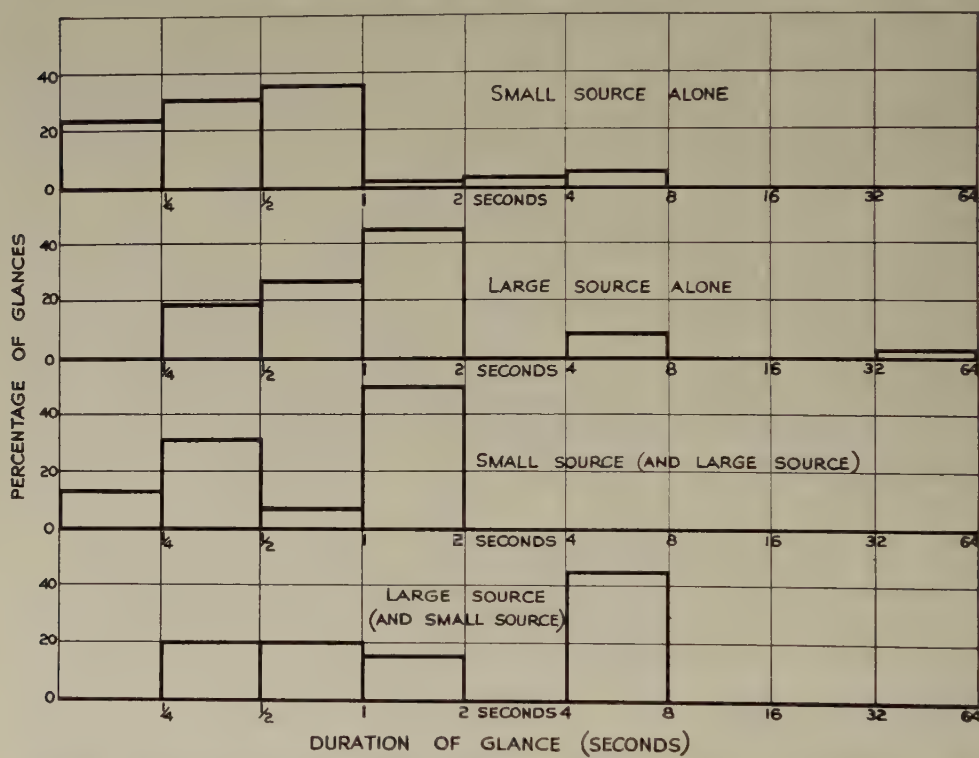


Figure 6. Analysis of phototropic effect of sources of large area and low brightness and of small area and high brightness presented separately and together in field of view.

Table 2. Further data concerning the results shown in Fig. 6

	Small source alone	Large source alone	Both sources together: Small source	Both sources together: Large source
Median time per glance (in seconds)	0·50	1·125	0·90	1·25
Number of occasions on which observers' eye movements were recorded	42	23	14	14
Number of glances	59	49	16	20
Total observing time (in minutes and seconds)	33 min 24 sec	22 min 0 sec	13 min 31 sec	13 min 31 sec
Percentage of total time spent looking at distracting source	2·32	7·56	1·57	6·32

could go on as long as the experimenter is able to make the analysis. The experiment has therefore been redesigned to make this possible, but no results have so far been obtained.

Ideally, the analysis of the eye movements should be made independent of any experimenter. Techniques for the analysis of eye movements, all involve, however, constraint on the subject, which causes difficulty and makes him very aware of the purpose of the experiment. This, as has already been mentioned, would be disastrous in these studies. A search continues for a truly objective means of determining the pattern of eye movements free of the objections of existing methods.

§ 4. Conclusions

It is too early to come to any detailed conclusions from the work. It does appear however, that the method may yield fruitful results, inasmuch as it is possible to analyse phototropic movements with some degree of precision and relate them to the physical environment.

One new conclusion has certainly arisen from the work so far, that is, that the gaze is fixed for longer periods on a large source of low luminance than on a small source of high luminance. This is important in lighting design. Attempts to eliminate uncomfortable glare have led to much re-design of lighting equipment to reduce surface brightness. The conclusion from the present work would suggest that such large low-brightness surfaces will command the attention and fix the gaze more often, or at least, for a longer period of time, than the older type of small high-brightness source. On the other hand, the results do not show that the low-brightness source is more *distracting* than the high-brightness source. The high-brightness source provokes a response in the form of a series of jerky darts towards and away from the source which may in fact be more fatiguing. Whether this is so or not we do not know. Further work, possibly of an entirely different nature involving direct subjective judgments will be necessary to establish matters of this kind.

4.1. *Applications*

The experimental work confirmed all too clearly Pollock and Bartlett's findings (1935) that effects which appear to be insistent in everyday life do not show up so clearly in controlled experiments.

The evidence obtained is clear enough, however, to lend experimental weight to the design of lighting which gives preferential brightness to the working area, so arguing in favour of local lights in suitable circumstances. It is of interest that, some time ago, a re-lighting of the carpenters' shop at the Building Research Station based on these principles produced a satisfactory result (Allen and Hopkinson 1951). Figure 7 shows a planing machine before re-lighting. Although the level of incident illumination was adequate by current standards, complaints were made, which were traced to the reflection from the polished machined surface, distracting the attention from the cutters and guide. Re-lighting with a changed position of the fitting, re-designed to give a lower brightness reflection, made the cutters and guide now the centre of attraction (Fig. 8). The reflection which was initially a phototropic *distraction* now became an *attraction*.

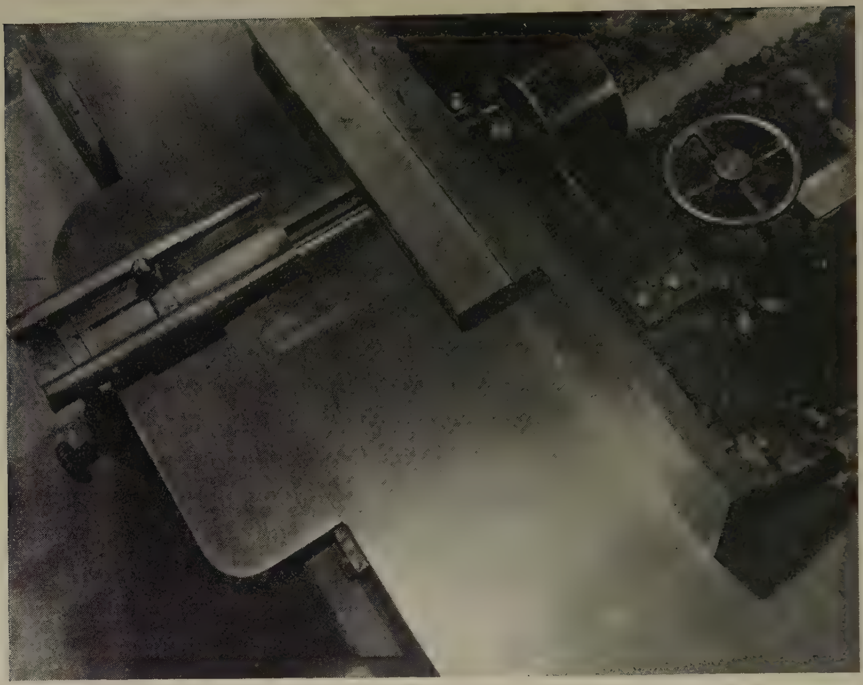


Figure 7. Reflection from polished surface of planing machine distracts attention from the cutters.

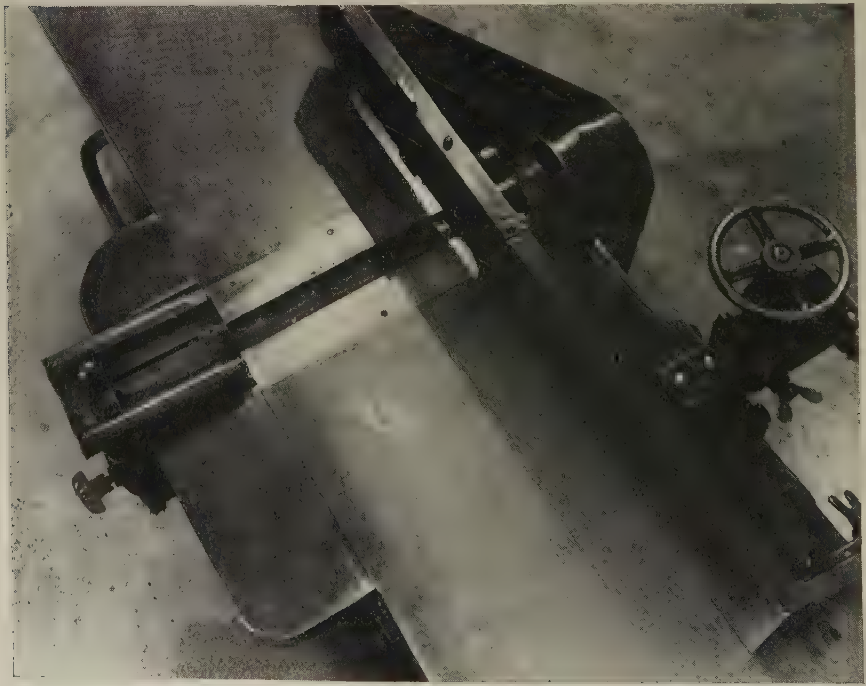


Figure 8. Relighting of the planing machine gives a lower brightness reflection and makes the cutters the centre of attraction.

Attention to these phototropic principles has assisted in the lighting of hospitals and schools. Empirical studies of colour attraction have also been made, and applied to the design of colour schemes, in conjunction with lighting in school classrooms.

The work described in the paper is part of the programme of the Building Research Board of the Department of Scientific and Industrial Research, and the paper is published by permission of the Director of Building Research. The authors express their gratitude to the observers who assisted in the experiment.

Dans la période entre les deux guerres, on avait adopté un éclairage d'ensemble donnant une illumination uniforme au niveau du plan de travail. Auparavant, on avait coutume d'éclairer localement l'endroit de travail.

On a cependant trouvé que l'éclairement général uniforme n'était pas toujours satisfaisant pour un travail exigeant de l'habileté visuelle et de l'attention à un degré élevé, et dans bien des cas, on avait préféré revenir à un éclairage local associé à une illumination générale.

On admet généralement que l'attention est soutenue par des objets qui contrastent fortement avec leur entourage, au point de vue de leur brillance, de leur couleur, de leur texture ou de leur forme. De même, l'attention peut être distraite par un objet brillant ou trés coloré se trouvant dans le champ visuel à peu de distance du point de fixation du regard. On a étudié expérimentalement le ' phototropisme humain '; on s'est servi d'un appareillage rendant possibles un enregistrement simultané ciné-photographique d'une scène visuelle et des mouvements oculaires d'un observateur qui voit cette scène sans savoir qu'il est lui-même observé. Le relevé du nombre de ces mouvements oculaires et de leur durée a révélé que des points concentrés très brillants distrayaient l'attention sous la forme de séries de mouvements oculaires saccadés, tandis que des surfaces moins brillantes mais plus étendues provoquaient davantage de mouvements oculaires de plus longue durée.

On a noté diverses modalités de comportement de différents observateurs; on a identifié deux groupes assez distincts qui présentent beaucoup de ressémblances frappantes avec les deux groupes de personnalités à 'répère postural' et à 'répère visuel' reconnus par Witkin en 1950.

On a suggéré quelques applications de ces résultats à l'éclairage des endroits de travail. Les résultats parlent en faveur d'un éclairement préférentiel du processus de travail lui-même, si possible par éclairage local.

Zwischen den beiden Kriegen wurde die Allgemeinbeleuchtung mit gleichförmiger Helligkeit über dem Arbeitsplatz eingeführt. Zuvor war die lokale Beleuchtung über der Arbeit üblich. Es wurde jedoch gefunden, dass Allgemeinbeleuchtung für Arbeit, die hohe Anforderungen an Sehgeschicklichkeit und Aufmerksamkeit stellt, nicht immer befriedigt. In vielen Fällen bevorzugte man die Rückkehr zu lokaler Beleuchtung, zusammen mit einiger Allgemeinbeleuchtung.

Es wird allgemein angenommen, dass die Aufmerksamkeit durch Objekte festgehalten wird, die einen starken Kontrast zu ihrer Umgebung zeigen, z.B. durch Helligkeit, Farbe, Oberflächenstruktur oder Form. In gleicher Weise kann die Aufmerksamkeit durch sehr helle oder farbige Objekte abgelenkt werden, die in einem etwas abseits vom betrachteten Objekt liegendem Gesichtsfeld sich befinden.

Es wurden Experimente über 'menschlichen Phototropismus' mit einem Apparat angestellt, welcher es ermöglichte, eine viselle Szene zugleich mit den Augenbewegungen eines unvoreingenommenen Beobachters dieser Szene zu kinematographieren. Die Zahl und Dauer dieser Augenbewegungen ergab, dass scharfe, äusserst helle Lichtpunkte die Aufmerksamkeit in einer Reihe sprunghafter Augenbewegungen ablenken, während weniger helle, grössere Flächen mehr langsamere Augenbewegungen hervorrufen.

Es wurden zwei verschiedene Verhaltensweisen verschiedener Beobachter bemerkt, die auffallende Ähnlichkeit mit den von Witkin (1950) beschriebenen Persönlichkeitsgruppen 'postural-clue' und 'visual-clue' zeigen.

Einige Anwendungen der Ergebnisse für die Arbeitsplatzbeleuchtung werden vorgeschlagen, sie liegen in der Richtung vorzugsweiser Lokalbeleuchtung.

References

Allen, W. A., and Hopkinson, R. G., 1951, Lighting of buildings. *J. R. Inst. Brit. Archit.*, **58**, 6, 222–225; 7, 272–278.

Pollock, K. G., and Bartlett, F. C., 1935, Psychological experiments on the effect of noise. *Industr. Hth. Res. Board Rep.* No. 65 (London: H.M.S.O.).

Witkin, H. A., 1950, Orientation to visual and postural vertical—individual differences in mode of space orientation, pp. 18–29 in *A Symposium on Psycho-physiological Factors in Spatial Orientation*, held in Pensacola, Florida, 1950, under the auspices of the U.S. Office of Naval Research, NAVEXOS P-966.

Woodworth, R. S., and Schlosberg, H., 1954, *Experimental Psychology* (New York: Henry Holt & Co.).

A LABORATORY APPROACH TO INTERPERSONAL ASPECTS OF TEAM PERFORMANCE

By Seymour Rosenberg

University of Kansas*

This paper brings together and re-appraises a number of studies, mostly already published elsewhere, from a laboratory research programme to deal in an experimental fashion with certain problems of team performance. An attempt has been made to be sufficiently comprehensive to anticipate a variety of team performance problems observed in the Air Force and other work-group settings. Research to date in this programme has dealt primarily with team training, although one may also note implications in this work for the problems of the distribution of displays and controls among team members.

The conceptual approach adopted is traceable to contemporary stimulus-response theories in psychology. Basic concepts and methods are briefly described followed by an analysis of stimulus-response arrangements in dyads. Feedback (reinforcing) stimuli in social settings are first given special attention since they seem central to almost any training problem.

Experiments are summarized which deal with parameters relevant to socially affected feedback. A number of task parameters are also given experimental consideration.

Finally, initial studies of discrimination learning within a team context, and the effects of individuals' past histories on a discrimination task, as these determine team outputs, are also described.

The human component in modern aviation and space flight receives considerable attention from scientists of various disciplines. Their research has resulted in important advances to overcome human limitations of an anatomical, physiological, or psychological nature, but has focused primarily on the efficient use of the individual considered as an isolated unit of action or as a part of a system consisting of one man plus a machine.

The individual is, however, usually not working alone with his machine. There is frequently at least one other person with whom he has commerce whether it be face to face, through verbal communication, or through the mediation of displays and controls. It is becoming apparent that these interpersonal aspects will play an increasingly important role as systems become more complex and as the requirements for coordination among system operators become more exacting. Whether one thinks of cys-lunar flight, ground-based missile operations, or electronic data-processing systems, social and experimental psychologists will be called upon to perform experimental research on the optimal distribution of displays and controls among team members, on the placement of operators with respect to each other, on the training of teams as teams, on the alleviation of isolation effects among small groups in novel environments, on the assembly of compatible individuals, and many other topics.

These problems are not unique but are assumed to be on a continuum with those faced by scientists who have studied the individual in a non-social environment. This is not to say, however, that it is fruitful, conceptually, to equate a team with an individual as some have done (Chapman and Kennedy 1956, Perlmutter and de Montmollin 1952). In considering team performance

* Now at the Bell Telephone Laboratories, Murray Hill, New Jersey.

problems, it is still important to emphasize that learning, fatigue, transfer, intelligence, etc. are characteristics of individual behaviour and not of group performance. 'Team training' or 'team learning' are abbreviations for behaviours that are learned by individuals in a social context.

Further thinking about these individual characteristics also points up the fact that the study of team problems will, no doubt, require additional technical developments to supplement those of individual psychology. Although it is an individual who learns, the specification of the independent variables of learning conditions to characterize *simultaneously* the situation for two persons on a team is novel. Independent variables appropriate to teams must incorporate the possibility that individuals on the team may each be in a different learning situation and that certain behavioural linkages relevant to the learning by each person may exist between these individuals. Prediction of behaviour by considering separately the situation of each individual on the team may not be possible, particularly when there exists some linkage between them. The dependent variables in team training are also novel since they include group as well as individual outputs. These considerations certainly argue for a vigorous and specialized scientific attack on 'team performance' problems with a view to providing the necessary additional concepts, methods, and substantive knowledge.

An integrated review is not considered feasible at this time because of the relative paucity of material and diversity of approaches. Readers who are interested are referred to the studies of Lanzetta and Roby (1956 a, b), Roby and Lanzetta (1956), Glanser and Glaser (1957 a, b), Glaser (1956) and Rand Corporation (Chapman and Kennedy 1956). The general intent of these various research programmes in team performance are similar, while methods and concepts differ considerably.

The present paper brings together a number of studies, some already published separately elsewhere, from a research programme in the U.S. Air Force Personnel and Training Research Center's Operator Laboratory. The programme was designed to deal with some problems of team performance in an experimental fashion. The research was conducted primarily within the laboratory in an attempt to be sufficiently comprehensive to anticipate a variety of team performance problems. While no specific systems are represented here, the concepts were developed to include factors common to a variety of operator teams observed in the Air Force, and possibly other work-group settings. The research conducted to date was directed primarily to team-training problems, although one can readily note a number of implications for the distribution of displays and controls among team members whose actions are highly interrelated. The laboratory research reported here is related to such questions as: What are the optimal feedback (knowledge of results) conditions to individuals on teams for producing individual and team accuracy? What is the optimal distribution of feedback information among team members (and, hence, instruments) to maintain the proficiency of individuals? Does a team-training method permit flexibility in the reassembly of teams? How do certain fixed task characteristics (e.g. the distribution of instruments) affect the choice of team-training methods?

The conceptual approach adopted here is traceable to contemporary stimulus-response (S-R) theories in psychology (Spence 1951). Hypotheses

are formulated in terms of the formal relationships among stimulus and response classes and the distribution of these classes among persons. Experimental situations are contrived to represent these formal relationships among persons.

Figure 1 indicates the essential stimulus and response units when a single psychological event is described for an individual. It shows the time relationships among: (*a*) the stimulus, which is termed the discriminative stimulus (S^d) and which sets the occasion for an act, (*b*) the act itself, or response (R) performed by an individual and (*c*) the state of affairs in which the individual finds himself after he has performed the response. We term this state of affairs the reinforcing or feedback stimulus (S^f). One may note that the event following a response may be the delivery of some tangible goal, value, reward, etc. For example, having stomach contractions around noontime (and/or noting the time of day) leads to activities which will result in getting lunch. Actually, in this example there is a large number of responses each followed by feedback stimuli. In most cases, then, the S^f is a sub-goal. These sub-goals then serve as discriminative stimuli for further responses. If, for example, an automobile is required to get to lunch, getting to the car is a sub-goal, or S^f, which also serves as a S^d for the next act, that of driving the car. In either case, S^f 'tells' the person something about how well he did—what his response has accomplished. There are a great many studies demonstrating the importance of S^f for learning and maintaining desired behaviour.

S^d (discriminative stimulus) ——	R(response) ——————→	S^f (feedback stimulus)
Examples:	Examples:	Examples:
a. Artificial horizon	a. Repositioning the stick	a. Change in the instrument
b. Stomach contractions	b. Going to a restaurant	b. Food
c. Instructor asks a question	c. Giving an answer	c. Praise
d. Effects of previous response	d. Change position of control	d. Information for next response

Figure 1. A single psychological event for an individual.

Now, what can happen to an S^f when someone is required to perform a task in a group context? One possibility is that nothing special happens. The response may affect the environment in such a way that no one else is involved and, hence, the S^f reflects only the adequacy of one person's behaviour. In effect, the individual will know how well he is doing no matter what the proficiency of his team-mate is. The following diagram illustrates such a situation.

$$\begin{array}{ll} \textit{Person A} & S^d \text{——} R \longrightarrow S^f \\ \textit{Person B} & S^d \text{——} R \longrightarrow S^f \end{array}$$

It can also happen, and quite frequently does happen, that the response of one person is somehow combined with that of another person to produce a 'confounded' S^f. The confounding is of the two responses, each performed by a different person. The feedback to a person is now affected by what his team-mate does as well as by his own actions.

The following diagram illustrates such a team relationship for *Person A* only.

$$\begin{tikzcd} \textit{Person A} & S^d \arrow[r, dash] & R \arrow[r] & S^f \\ \textit{Person B} & S^d \arrow[r, dash] & R \arrow[r] \arrow[ur] & S^f \end{tikzcd}$$

Examples are numerous. Consider a navigator in a B–52 aircraft who cannot determine his own celestial fixes. He is given readings from a sextant by the ECM operator and computes location on this basis. The navigational circular error as a S^f to either operator is a complex combination of the errors of each. Tasks may vary in the proportion of contribution of each person's response to the feedback. Some tasks may be extreme in this respect, i.e. *Person A* may contribute almost nothing to his S^f while *Person B* actually determines *A*'s feedback values. The following diagram illustrates this extreme condition for *Person A*.

$$
\begin{tikzcd}
\textit{Person A} & S^d \arrow[r, dash] & R & S \\
\textit{Person B} & S^d \arrow[r, dash] & R \arrow[r] \arrow[ur] & S^f
\end{tikzcd}
$$

Such an extreme social condition typically occurs when all team members are praised or somehow given an indication of a 'good' output for which the jobs of one or two members are completely irrelevant.

This preliminary analysis of socially affected S^f values led to a recent study by Rosenberg and Hall (1958). They varied the S^f to each member of a two-person team in the degree to which each determined his own S^f. The response was simply to turn a concealed cylindrical knob during a timed interval. Figure 2 is a sketch of the panel provided separately to each of the two persons. The amount each person turned the knob on a trial was recorded by an experimenter. The S^f value was then computed and displayed by the experimenter with a movable pointer on the scale mounted on the panel.

The S^f to one sample of persons contained information only about the adequacy of a person's own response after each of 50 trials. This condition is termed 'direct' feedback. Optimal preference in this condition consisted of turning the knob exactly four times on each trial. A second feedback condition, given to another sample of persons, consisted of a feedback in which the responses of the person and his partner were *averaged* and only the average value was presented to a person after each trial. The required *average* value was again four turns. This condition is termed 'confounded' feedback. Thus, the optimal performance in this condition cannot be specified for an individual without regard to the behaviour of his partner. The optimal performance of the *team* is a sum of eight turns distributed between the two subjects in any fashion. Finally, as the third feedback condition, the extreme of the continuum was used. Each person in this sample was given feedback after each of 50 trials, not on the adequacy of his own response at all, but only on the adequacy of his partner's response. If the *partner* turned his knob four times, the person would get a perfect S^f value. This feedback condition is termed 'other's' feedback.

In general, two types of measures are of interest to us in these situations. One is the learning, i.e. the improvement of accuracy over a series of trials, by an individual as a function of the type of S^f received; and the other is the changes in the team product or group output as a function of the S^f's delivered to each of the individuals in the group.

Figure 3 shows the results of the experiment when individual accuracy is measured. Smaller values on the ordinate indicate greater accuracy. A

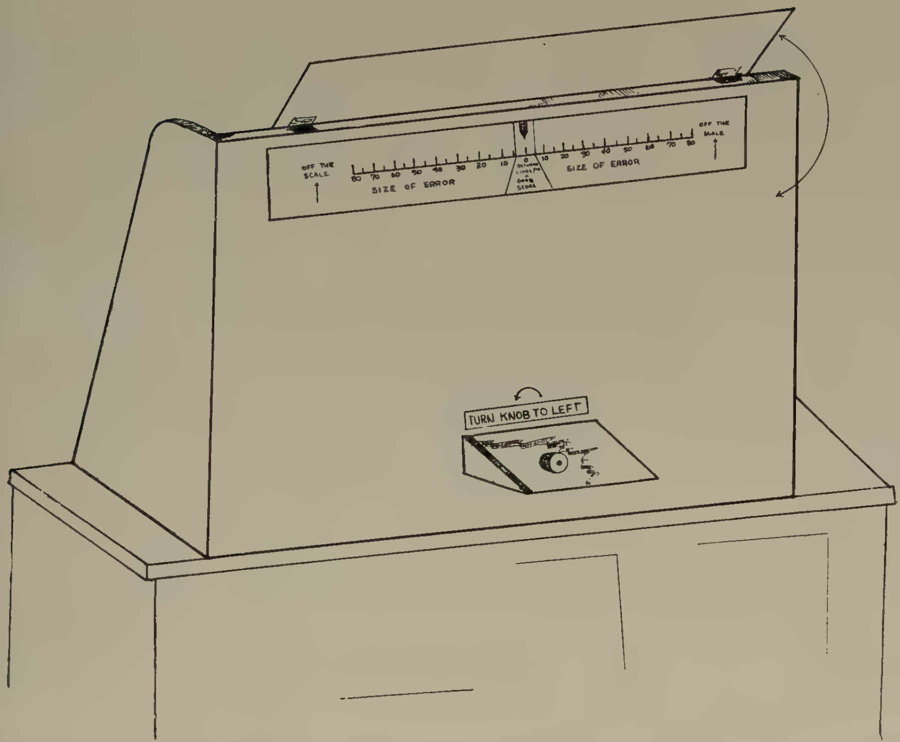


Figure 2. A sketch of the panel facing each of two subjects. (See Hall 1957, Rosenberg and Hall 1958.)

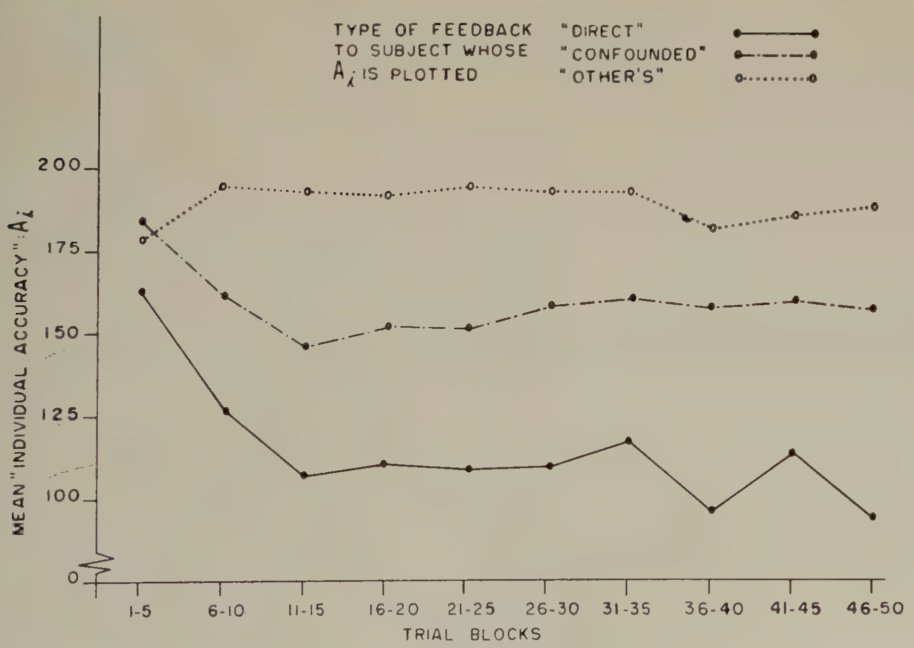


Figure 3. Differences among samples of subjects in their mean individual accuracy (A_i) as a result of differences in the feedback conditions among the samples. (Rosenberg and Hall 1958.)

fairly simple and clear relationship exists between individual accuracy and type of feedback. An individual learns more rapidly and reaches a higher level of proficiency on a task when his feedback is ' direct ' than when it is ' confounded ' by someone else's behaviour. There seems to be virtually no improvement when a team task is so arranged that S^f is ' other's ' i.e. the S^f to an individual contains no information about his own behaviour.

Let us now look at the team product. Figure 4 shows the curves for the team accuracy measure. Again, smaller values on the ordinate indicated greater accuracy. Note that team accuracy is not affected by the feedback in the same way as individual accuracy. In this case ' confounded ' feedback to an individual does *not* result in a poorer contribution by him to the team product than does ' direct ' feedback to him. In fact, in a replication of the experimental analysis reported in Fig. 4, ' confounded ' feedback appeared to result in development of a better team product than providing ' direct ' feedback to individuals. The replication results are shown in Fig. 5.

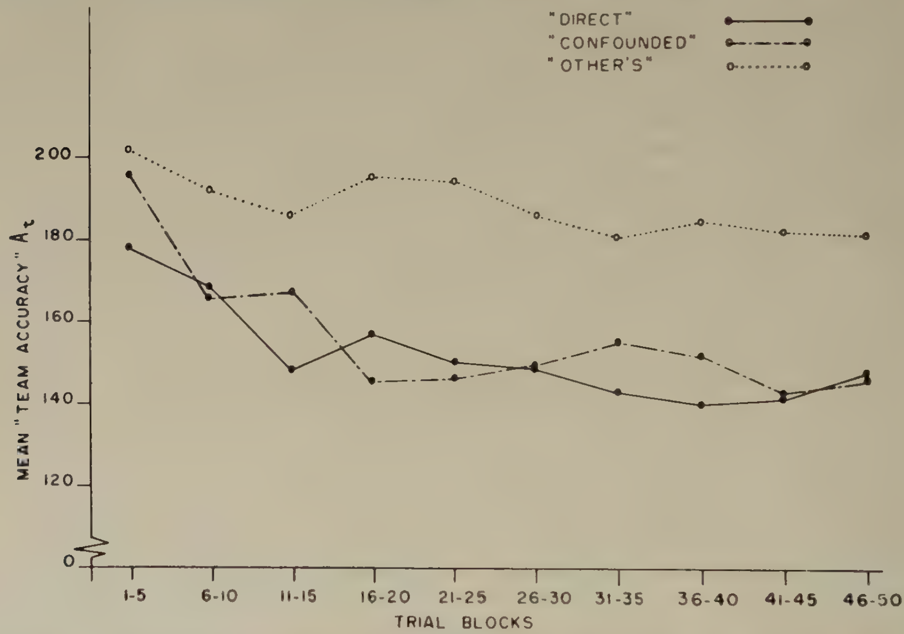


Figure 4. Differences among samples of subject-pairs in their mean team accuracy (A_t) as a result of differences in the feedback conditions among the samples. (Rosenberg and Hall 1958.)

Team accuracy, therefore, can be improved considerably even if two untrained persons are assembled and given a ' confounded ' S^f only. This fact has now been verified in a number of different studies. The finding is impressive, but there are certain limitations which must be considered. For one thing, flexibility in reassembling or reshuffling teams has been lost. On Team X, for example, two persons have learned to adjust to each other in their own way so as to produce a good team score. On Team Y, consisting of two other persons, the adjustment may be as good, but the manner of adjustment is quite different from that of the first team. If two new teams were now formed by taking one member of each of the original teams, a period

of readjustment would be required. It would seem, therefore, that in some systems where team integrity cannot be maintained, it is necessary that individual accuracy be made to conform to certain requirements.

As we noted, individual accuracy may never develop with a confounded S^f. Suppose, however, that all individuals were first given 'direct' feedback before assembly into teams. That is, they are given standard individual training. The question is then posed: 'Can individual accuracy (i.e. standardized behaviour) once acquired, be maintained under various social feedback conditions and, hence, effective reassembly readily accomplished? These considerations suggested another experiment reported by Rosenberg (1959).

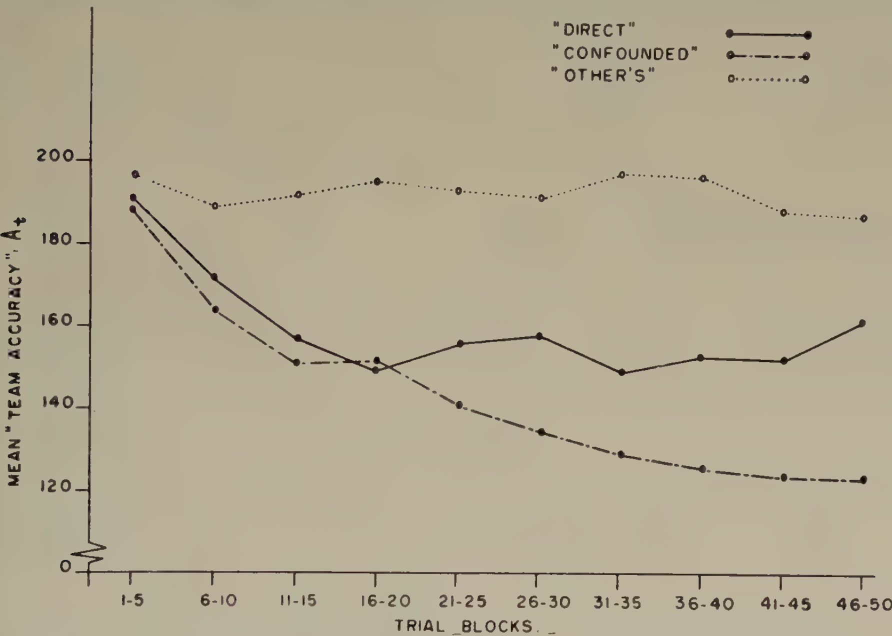


Figure 5. A replication of the study shown in Fig. 4. (Rosenberg and Hall 1958.)

The procedure consisted of giving all persons 25 trials, using direct feedback and retaining those persons who had given evidence of learning. Then, pairs of persons were assembled and given either 'direct', 'confounded', or 'other's' feedback. The results, shown in Fig. 6, demonstrated quite clearly the rapid deterioration of individual accuracy when feedback contained information about someone else's response. As before, when the S^f was information exclusively about another's behaviour, individual accuracy could not be maintained.

If we may extrapolate, this study points up the limitations of individual specialist training in maintaining standardized individual behaviour under certain team conditions. However, in combination with the results of another study by Hall (1957), it may be concluded that a standardized *team output* (rather than individual output) is unaffected by the amount of individual pretraining as long as both team members are getting, as an S^f, values which are partially contingent upon their own behaviour. The minimum proportion of a person's behaviour which must be present before a team product is affected adversely remains an empirical question.

Finally, it might be interesting to study the effects of direct feedback trials interspersed periodically among social feedback trials in maintaining standardized individual behaviour. Such a procedure might prove effective in certain field settings where team members are typically provided with social feedback but where periodic standardization of individuals is feasible.

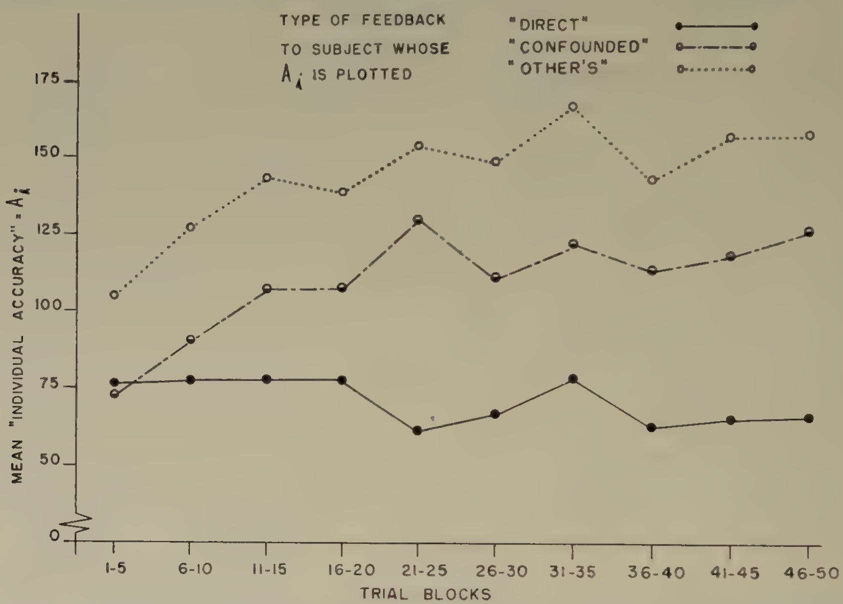


Figure 6. Differences among samples of subjects in their mean individual accuracy (A_i) as a result of differences in the feedback conditions among the samples. Results were obtained following a period of ' direct ' feedback for all subjects. (Rosenberg 1959.)

To what kinds of tasks are these findings limited? In the study just described, direct feedback could also be stated to mean that no one could help the person if his response consistently fell short of the goal or overshot it. In other words, the response of a person must assume a unique value to obtain a perfect score. In ' confounded ' feedback, on the other hand, there is no fixed size for the response. Indeed, if one of the two persons does not turn his knob at all while the second person turns it the required magnitude, *both* will obtain a perfect score. This relationship is reciprocal in that either person can do the work for both. It is also termed ' compensatory ' because one person can compensate for an inaccuracy of his partner. In contrast the feedback value could be so computed that both persons must contribute equally in response. Thus, for example, the task could require one person to contribute exactly the same as his partner before either gets a perfect score. This relationship would not be compensatory. A pure case of a non-compensatory relationship in which S^f is ' confounded ' would occur if, in bombing, one person were responsible for range and the other for deflection while S^f is given in circular error only.

The degree of compensatory relationship between team members is only one of a number of task variables which relate to team performance. Work has also been started on tasks where the response of one person is available

as an S^d to a second person before the latter performs his own response. This may be represented diagrammatically as follows:

$$\begin{tikzcd}
\textit{Person A} & S^d \arrow[r, dash] & R \arrow[d] \arrow[drr] & S^f & \\
\textit{Person B} & & S^d \arrow[r, dash] & R \arrow[u] \arrow[r] & S^f
\end{tikzcd}$$

The S^f values in this diagram are shown as 'other's' for Person A 'confounded' for Person B. This is probably a typical S^f structure in many systems. Note, of course, that any of the variants in feedback distribution described above may also be instituted in such a task. For example, Person A may receive 'other's' feedback while Person B receives 'direct' feedback. This is represented diagrammatically:

$$\begin{tikzcd}
\textit{Person A} & S^d \arrow[r, dash] & R \arrow[d] & S^f & \\
\textit{Person B} & & S^d \arrow[r, dash] & R \arrow[u] \arrow[r] & S^f
\end{tikzcd}$$

The formulation of variables appropriate to interpersonal action and the execution of empirical studies involving these variables begin to amplify our understanding of group output and of individual performance within specified team contexts. For example, the common practice of simply putting people together after they have had some amount of individual specialist training and letting them learn to operate as a team must be adopted with care. Even the more sophisticated statement, 'Train the team as a whole in an adequately simulated environment and give it knowledge of results,' (Chapman and Kennedy 1956) appears to over-simplify team-training problems. Use of feedback conditions is contingent on our objectives. If we wish a team product, one procedure is suggested. If we wish flexibility in reshuffling teams, another feedback condition for individuals is required. Pervading these facts are considerations of task structure, e.g., compensatory relationships among the team members. Other characteristics of the task, which space does not permit me to describe, must also be subjected to investigation. These task variables were recently described to some extent in a paper by Hall and Rosenberg (1957). A vigorous empirical programme is now required to further our understanding of social feedback as it determines performance and to clarify and refine our concepts further.

The studies described so far have been concerned almost exclusively with the relationship between a single response class and a fixed S^d of each of two team members and the S^f which follows such a response. We have also begun studying performance problems which arise when a number of responses are available to each team member and, hence, a number of S^d values are presented either simultaneously or successively. The distinction between a fixed S^d and a variable S^d is frequently made by learning theorists. The first is usually termed trial and error or operant learning while the latter is termed discrimination learning.

For this study, a somewhat different experimental task has been used—one which was more suited to studies of this type of system. Figure 7 is a sketch

of the booth in which each person sat. The display to each of the two persons was three sets of lights, each set containing a green, red and white light arranged in a triangle. The controls for each subject consisted of three switches arranged in a row. The equipment was so constructed that both persons always had the same display. The controls were also paralleled so that the operation of Switch No. 1 in either booth changed the display in the same way in both booths. When a trial began, one light from each triangle of lights lit up. When either person pushed a switch, one, two, or all three lights would go out and a new set of lights would go on. The goal was defined for the team as getting three red lights on. Teams were given a number of trials to improve their efficiency at this task.

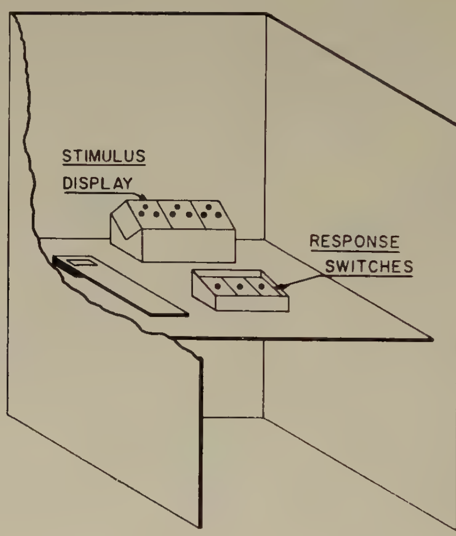


Figure 7. A sketch of the booth for each subject in the discrimination task. (Zink 1957.)

The first study by Zink (1957), involved a rather straightforward exploration of the *relationship* between the discriminative stimuli (or display) and the responses (or operation of controls). Zink manipulated this relationship so as to create either a simple display-control relationship for team members or complex (difficult) display-control relationship. A team was also composed of two persons. To one set of teams he gave a number of trials on a simple task. To another set of teams he administered the complex task. The differences in difficulty and rate of improvement of the two sets of teams are shown in Fig. 8, which sets out the average numbers of errors made by teams on the two tasks. This finding is not startling since the task was manipulated and pretested so as to produce large differences in error scores. We are, however, interested in a new dependent variable, i.e., the way team members distribute responsibilities. This was measured by noting which team member made the correct responses on each of the three controls on each of the trials. Figure 9 is a graphic summary of the results. If either person tended to dominate a control, the measure noted this as a large value. If no clear differentiation of responsibility existed, the measurement value was small. Results rather clearly indicate that there is little distribution of responsibility

when the task is complex compared with the simple task. Nor is there any indication of a trend in results for the complex task. This finding, coupled with the poor learning on the complex task, suggests an hypothesis. That is, in the complex task, team members know too little about the task itself to

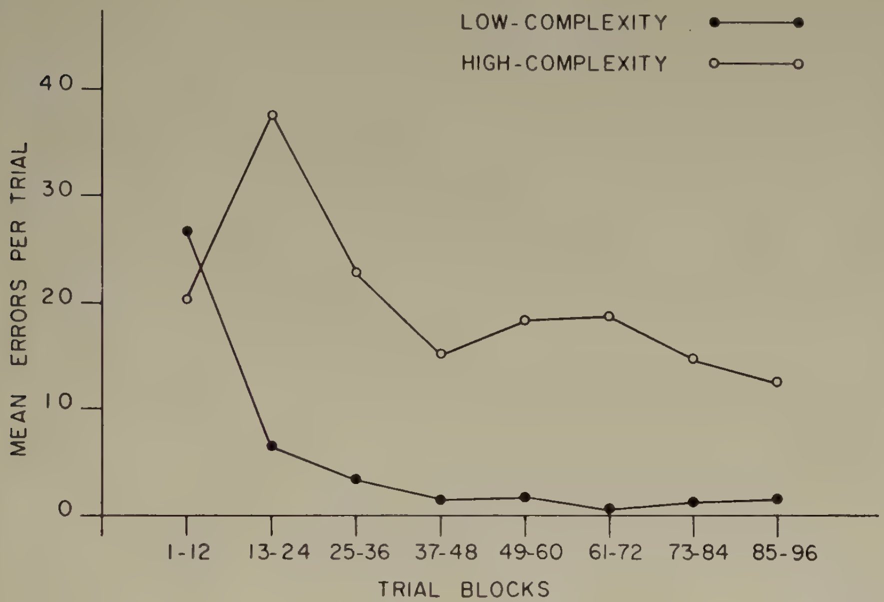


Figure 8. Differences between two samples of subjects in mean number of errors as a result of differences in complexity of task. (Zink 1957.)

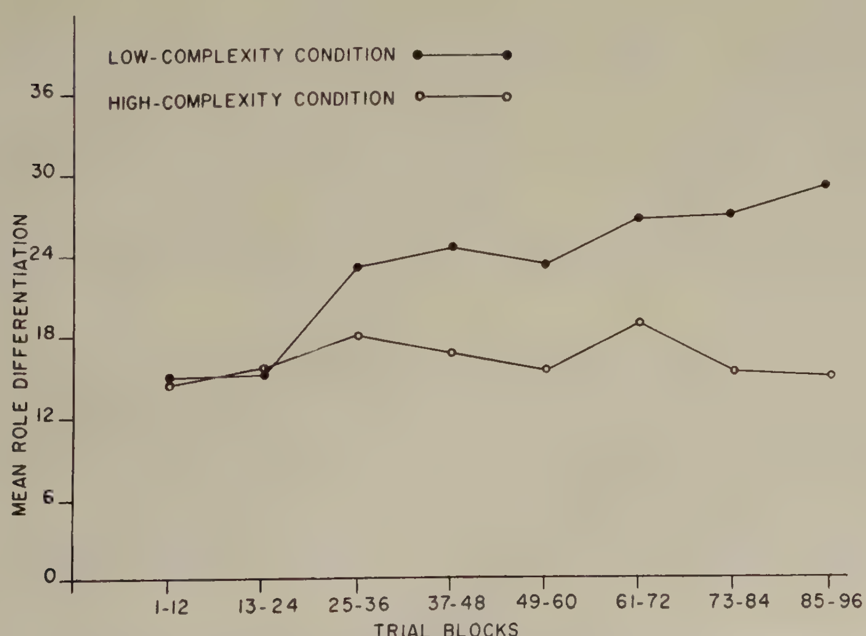


Figure 9. Differences between two samples of subjects in their mean role differentiation as a result of differences in complexity of task. (Zink 1957.)

reach the more advanced type of learning; i.e. learning to adjust to each other's behaviour.

A preliminary study on this question was recently performed by Rosenberg (unpublished). Some individuals, before they were assembled as a team, engaged in sufficient practice to learn to solve the task alone. Other individuals were given no practice on the task. Three types of assembly were then performed, i.e. pairs consisting of one trained and one untrained person, pairs consisting of two trained persons, and pairs consisting of two untrained persons. Distribution of responsibility was then measured on the tests after assembly. The results are shown in Fig. 10. Statistical tests fail to demonstrate any differences among pairs assembled with different individual past histories.

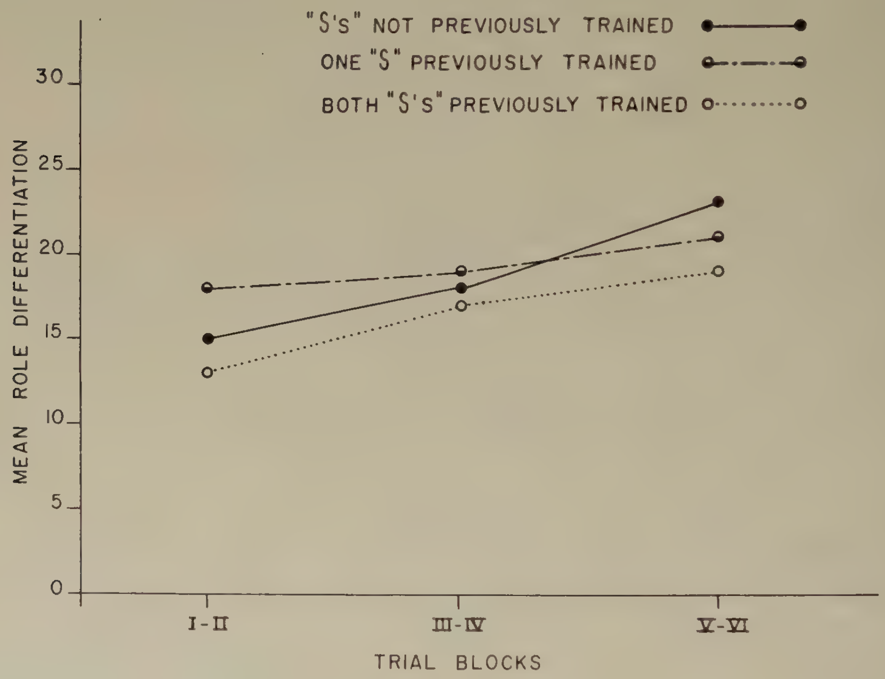


Figure 10. Differences among samples of subjects (S's) in their mean role differentiation as a result of differences in the assembly of past histories of individual training. (Unpublished study.)

Indeed, as we examine the graph, there is some indication that when both persons are pretrained, distribution is somewhat poorer. Tentatively, then, we must conclude that the distribution of responsibility is difficult to develop when the task is complex, at least within short periods of time, and that this failure is not due exclusively to ignorance of the task. This is a rather fascinating discovery and will, of course, be examined much more closely. There are some implications here concerning the phasing of individual and team training when responsibilities must be distributed among the group. Certainly the contention that individual training before assembly into teams automatically assures optimal team performance must be explored in greater detail.

This research was done under A.R.D.C. Project No. 7737, Task No. 27006, in support of the research and development programme of the Air Force Personnel and Training Research Center, Lackland Air Force Base, Texas. Permission is granted for reproduction, translation, publication, use and disposal in whole and in part by or for the United States Government.

Cet article réunit et ré-évalue un certain nombre d'études, la plupart déjà publiées ailleurs, faisant partie d'un programme de recherche en laboratoire qui porte sur divers problèmes de performance en équipe, abordés d'une façon expérimentale. On a essayé d'être suffisamment général au départ pour répondre d'emblée à une variété de problèmes de performances en équipe dans l'Aviation et dans d'autres situations de travail de groupe. Les recherches entreprises jusqu'à ce jour dans le cadre de ce programme ont porté avant tout sur l'entraînement en équipe, encore que l'on puisse remarquer que ce travail touche aussi aux problèmes de la répartition des signaux à utiliser et des commandes à effectuer, entre les membres d'une équipe.

L'approche conceptuelle adoptée procède des théories contemporaines relatives aux mécanismes stimulus-réponse en psychologie. Les concepts de base et les méthodes sont décrites brièvement et suivis par une analyse des arrangements stimulus-réponse dans le groupe de deux sujets (dyade). On a porté tout particulièrement l'attention sur les stimuli de retour ou de feed-back (de renforcement) car ils paraissent essentiels dans la plupart des problèmes d'entraînement.

On y résume des expériences qui font entrer en jeu des paramètres relatifs à un feedback affecté par un facteur social. Plusieurs autres paramètres caractéristiques de la tâche sont également étudiés expérimentalement.

Finalement, on décrit des études préliminaires sur l'apprentissage discriminatoire dans un contexte d'équipe, et les influences des antécédents individuels sur l'exécution de la tâche de discrimination, dans la mesure où ceux-ci affectent les rendements des équipes.

In dieser Arbeit wurden eine Reihe meist schon veröffentlichter Untersuchungen eines Laboratoriums-Forschungs-Programmes zusammengestellt und neu bewertet, die sich experimentell mit bestimmten Problemen der Gruppenarbeit befassten. Es wurde versucht, die Versuche genügend zu erweitern, um verschiedene Gruppenarbeits-Probleme, die bei der Luftwaffe und bei anderer Zusammensetzung von Arbeitsgruppen beobachtet wurden, vorauszusehen. Die bis heute durchgeführte Forschung beschäftigte sich hauptsächlich mit Gruppentraining, wenn auch Ansätze für eine Bearbeitung der Probleme der Verteilung und Anordnung der Steuerorgane auf die einzelnen Mitglieder der Gruppe zu vermerken sind.

Die grundsätzliche Art des Vorgehens stützt sich auf die gegenwärtige psychologische Theorie der Reizbeantwortung. Die grundlegenden Ansätze und Methoden wurden kurz beschrieben und die paarweise Reizbeantwortungs-Anordnung analysiert. Verstärkende Rückkoppelungs-Reize in sozialen Gruppen erweckten Aufmerksamkeit, seit sie in jedem Trainings-Problem im Mittelpunkt zu stehen scheinen.

Experimente wurden zusammengestellt, die sich mit Faktoren befassen, die diese sozial bedingte Rückkoppelung beeinflussen. Auch eine Reihe Aufgaben-Parameter wurden experimentell untersucht.

Schliesslich wurden Anfangsversuche darüber beschrieben, wie sich das individuelle Unterscheidungsvermögen in der Gruppenarbeit auswirkt und wie Schulung des Unterscheidungsvermögens in einer Gruppe verläuft.

References

Chapman, R. L., and Kennedy, J. L., 1956, The background and implications of the systems research laboratory studies. In Finch, G. and Cameron, F. (Eds.), *Symposium on Air Force human engineering, personnel and training research.* (A.R.D.C. Technical Report 56–8) Baltimore: Air Research and Development Command.

Glanzer, M., and Glaser, R., 1957 a, *Techniques for the study of team structure and behavior. Part I: Analysis of structure.* Office of Naval Research Technical Report. (Pittsburgh: American Institute for Research); 1957 b, *Techniques for the study of team structure and behavior. Part II: Empirical studies of the effects of structure.* Office of Naval Research Technical Report. (Pittsburgh: American Institute for Research).

Glaser, R., 1956, *Descriptive variables for the study of task-oriented groups.* Technical Report. (Pittsburgh: American Institute for Research).

Hall, R. L., 1957, Group performance under feedback that confounds responses of group members. *Sociometry,* **20,** 297–305.

HALL, R. L., and ROSENBERG, S., 1957, An S-R analysis of social interaction. *Amer. Psychologist*, **12,** 370. (Abstract).

LANZETTA, J. T., and ROBY, T. B., 1956 a, Effects of work-group structure and certain task variables on group performance. *J. abnorm. soc. Psychol.*, **53,** 307–314; 1956 b, Group performance as a function of work-distribution patterns and task load. *Sociometry*, **19,** 95–104.

PERLMUTTER, H. V., and DE MONTMOLLIN, GERMAINE, 1952, Group learning of nonsense syllables. *J. abnorm. soc. Psychol.*, **47,** 762-769.

ROBY, T. B., and LANZETTA, J. T., 1956, Work group structure, communication, and group performance. *Sociometry*, **19,** 105–113.

ROSENBERG, S., 1959, The maintenance of a learnt response in controlled interpersonal conditions. *Sociometry*, **22,** 124–138.

ROSENBERG, S., and HALL, R. L., 1958, The effects of different social feedback conditions upon performance in dyadic teams. *J. abn. soc. Psychol.*, **57,** 271–277.

SPENCE, K. W., 1951, Theoretical interpretations of learning. In S. S. Stevens (Ed.), *Handbook of experimental psychology* (New York: John Wiley & Sons, Inc.).

ZINK, D. L., 1957, The development of role differentiation in dyads as a function of task complexity. *Amer. Psychologist*, **12,** 371. (Abstract).

PERSONNEL VARIABLES IN THE ANALYSIS OF MAN–MACHINE SYSTEMS

By Martin I. Kurke
Dunlap and Associates, Inc., Washington 4, D.C., U.S.A.

In an experiment comparing the detectability engendered by four optical systems, additional data concerning certain characteristics of the subjects were collected. Analysis of the data led to the conclusion that although variations of equipment design produced significant differences in the performance of a simple psychomotor task, the personnel variables of mental ability and attitude also had significant effects. It is suggested that the design of a man–machine system should take into account both personnel and design considerations if the best human contribution to the system's effectiveness is to be achieved.

One type of human factor in the design of complex equipment largely ignored by practising human engineers is what may best be called the ‘personnel variables’. These are associated with selection and placement, attitudes and morale, and the training of the individuals who must operate the system. Of these variables only training has, until recently, received any systematic attention from the human engineer. Only one paper (Abt 1948) known to the writer relates personality variables to equipment design. There is, however, an article (Anon 1958) in a trade journal which indicates that studies relating the effectiveness of space flight crew to personality for the purpose of system design are under way. Other personnel traits which have been investigated, but only peripherally, in terms of system development, are degrees of literacy (Richardson *et al.* 1953), various aspects of intelligence and intellectual processes (Vince 1953, Ellis and Sloan 1957, Grice 1957, Kaczkowski and Connery 1958), and attitudes (Roethlisberger and Dixon 1943, Berkowitz 1954, Knoell and Stice 1954). The study of these variables in relation to specific equipment problems, however, does not usually lie within the field of investigation of the engineering psychologist. Thus, in their reports of unsuccessful attempts to isolate equipment variables for the control of empty field myopia, both Brown (1957) and the present writer concede that the solution of that problem may lie in selection procedures rather than in equipment design.

The present writer was recently assigned the task of determining which of five proposed optical systems is psychophysiologically optimal for inclusion in a certain proposed weapon system. It was decided to compare the optical systems empirically, and at the same time to use this opportunity to investigate quantitatively the effects, if any, of two personnel variables upon the ability to detect airborne targets with the optical systems involved. The specific variables under study were *mental ability* (as indicated by the Otis test) and *attitude toward the army*. These variables were chosen because they are believed to be two of the major sources of subject variance and to be unrelated to each other.

§ 1. Apparatus and Procedure

The study was performed at the Ordnance Test Activity, Yuma Test Station, Arizona, in March 1957. This location was chosen because it is an

area of good weather and clear visibility ; it afforded control of restricted airspace ; and aircraft targets were available.

Five monocular optical devices were made available to determine the maximum range at which aircraft could be detected with each. The devices were mounted on tripods and fixed in azimuth and elevation so that the field of view did not include features of the terrain. A push-button switch was mounted on each tripod for the subject's use. The switches were connected to a ten-channel Esterline–Angus Recorder installed in an M33 radar van.

Target course was plotted by the radar and range data were relayed to the recorder. The target, an F–86 aircraft, flew a predetermined head-on course which remained in the field of view of the optical devices from 21 000 to 4000 yards (slant range) at a speed of 250 knots at 3000 feet above the ground. Radio contact provided ground control of the aircraft at all times.

Thirty military personnel were detailed to serve as subjects for the experiment. Their visual acuity, tested on the Bausch and Lomb Orthorater, ranged from 20/15 to 20/30 (Snellen) for the uncorrected, preferred eye.

A latin square design was followed to allow each subject to detect the target with each optical system four times, the first of which was a practice session. The subjects were instructed to look through the optical systems at a given signal and to press the button as soon as the target was detected. The detection data were recorded as range information on the Esterline–Angus Recorder. At a second signal the subjects moved to the next optical system and waited for the signal to sight again.

No false runs were made for control purposes. The aircraft appeared in the field of view on each trial.

During testing the sky was clear or contained scattered clouds which gave less than 10 per cent cover above 10 000 feet. Visibility was greater than 30 miles.

After testing each subject was given the Otis Self-Administering Test of Mental Ability. About half of the men were rated as below average, and most of the others were in the average range. In addition, all subjects rated their attitudes toward the army on a 5-point Likert-type scale. Half the men had favourable or highly favourable attitudes ; the others had neutral or negative attitudes. There was no significant correlation between attitude and mental ability ($r = -0{\cdot}103$). It was possible, therefore, to dichotomize the variables into Average versus Low Mental Ability, and Favourable versus Non-favourable Attitude toward the army.

§ 2. Results

An analysis of variance, shown in Table 1, was computed with mental ability, attitude and four optical systems as independent variables and detection range as the dependent variable. The results for the fifth optical system showed marked qualitative differences from those for the other four (Kurke and McCain 1957) and were not therefore considered further in the present context as they were not regarded as comparable. Differences in optical systems proved significant at the 0·01 level. Attitude toward the army also provided a source of variation : those with the favourable attitudes detecting targets at a significantly ($p < 0{\cdot}01$) closer range than those with less favourable attitudes. Mental ability differences also provided significant differences in detection

ranges ($p < 0{\cdot}05$): those with average and better mental ability detecting at a mean range of 16 880 yards, while those subjects below average detected at only 16 120 yards. The figures are set out in Table 2. The interaction of mental ability and attitude also provided significant differences at the 0·05 level; those with non-favourable attitude and low mental ability detecting at the greatest range. Poorest detection was made by those with favourable attitudes and low mental ability. The optical systems used did not interact with either of the two personnel variables to produce significant differences in detection ranges. We may therefore conclude that in the present instance the equipment variables are independent of the personnel variables.

Table 1. Summary analysis of variance

Source	*df*	Mean square	*F*
Between Optical systems	3	69·86	16·63‡
Mental ability	1	21·62	5·15†
Attitude	1	29·96	7·13‡
Inter: OS × MA	3	4·17	0·99
MA × Att	1	22·12	5·27†
OS × Att	3	8·70	2·07
OS × MA × Att	3	3·02	0·72
Residual	104	4·20	—
Total	119		

† $p<0{\cdot}05$; ‡ $p<0{\cdot}01$.

Because the measures collected were replicable in one independent variable but not in the other two, the data were analysed by the method shown in Table 1. It will be recognized that the residual term represents individual differences both within and between subjects. There might then, be reason to suspect some inflation in the reported F-values for the personnel variables. However, it is believed that the size of the obtained F ratios are such that any correcting degradation resulting from a different treatment of the data would not materially alter the significance of these results.

Table 2. Mean detection ranges (yards) as a function of personnel variables

Mental ability	Attitude		Mean
	Favourable	Non-favourable	
Average	16930	16820	16880
Low	15130	17100	16120
Mean	16030	16960	—

§ 3. Discussion

The personnel variables contribute about half the significant variance in this simple man–machine system. The usual analysis of experimental data in human engineering studies incorporates personnel variables with error or residual variances. The implications for future work appear to be clear. Either the investigator and the ultimate user must carefully select the individuals to operate each separate type of equipment, or they must know

that whatever equipment they use is designed to be operable by as many types of people as possible. The former choice may require a complex personnel classification system taking into account all pertinent personnel variables in relation to all types of equipment. Even if such a complex system could be designed and made workable, the exigencies of a manpower shortage would most likely necessitate the not too expeditious placing of square pegs in round holes.

If, on the other hand, the aim of human engineering, namely the design of equipment for use by the median 90 per cent of the population, is to be achieved, personnel variables of significance to equipment design must be systematically identified and accounted for in all human engineering research and development programmes. Present trends in systems analysis, such as the application of an initial theoretical analysis of the complete system, early phasing-in of human factors considerations in systems development, and design of the system for the maximum human contribution to its effectiveness would seem to indicate the need to include the personnel psychologist as one of the systems development team.

The author wishes to express his gratitude to his friend and colleague, Lewis Estrine. The present study grew out of a series of discussions with him over a period of several months.

Dans cette expérience qui compare le pouvoir de détection de 4 systèmes optiques, des données supplémentaires sur certaines caractéristiques personnelles des sujets ont été réunies. L'analyse des données amène l'auteur à conclure que si des variations de la structure de l'équipement provoquent des différences sensibles dans la performance d'une tâche psychomotrice simple, les variables personnelles telles que le niveau intellectuel et l'attitude engendrent elles aussi des effets significatifs. Dans l'organisation d'un système homme–machine il y a donc lieu de prendre en considération à la fois la structure de l'équipement et la personnalité des opérateurs, de manière à assurer la meilleure contribution du facteur humain à l'efficacité du système.

In einem Experiment, in dem die Fähigkeit, mit 4 monokularen Fernrohren Flugzeuge zu entdecken, verglichen wurde, wurden charakteristische Daten der verschiedenen Versuchspersonen gesammelt. Eine Analyse dieser Daten führte zu dem Schluss, dass, wenn auch die Aenderungen der Ausführung der Instrumente grosse Unterschiede bei der Leistung dieser einfachen psychometrischen Aufgabe ergab, doch auch die persönlichen Variablen der geistigen Fähigkeit und Haltung bedeutende Unterschiede bringen. Es wird angeregt, beim Entwurf von Mensch–Maschine-Systemen beide Momente in Rechnung zu stellen, die persönlichen und die konstruktiven, um den besten Erfolg zu erzielen.

References

Abt, L. E., 1948, Contribution to human engineering: 2. An overall view of personality for the human engineer. *N.Y. Univ. Res. Div. Coll. Engng*, October.

Anon, 1958, Work helps man endure space isolation. *Aviat. Week*, 17 March, 37–47.

Berkowitz, L., 1954, Studies in group norms: The perception of group attitudes as related to criteria of group effectiveness. *USAF Pers. & Trng Res. Cent.* Tech. Rep. 54–62.

Brown, R. H., 1957, 'Empty field' myopia and visibility of distant objects at high altitudes. *Amer. J. Psychol.*, **70**, 376–385.

Ellis, N. R., and Sloan, W., 1957, Rotary pursuit performance as a function of mental age *Percept. Motor Skills*, **7**, 267–270.

Grice, G. R., 1957, On the relations between discrimination reaction time, anxiety, and intelligence. *J. abnorm. (soc.) Psychol.*, **55**, 146–147.

Kaczkowski, H. R., and Connery, T. F., 1958, PMA factors as predictors of high school workshop performance. *Psychol. Nwsltr.*, **9**, 232–233.

Knoell, D. M., and Stice, G. F., 1954, Development of attitude scales relevant to combat crew membership. *USAF Pers. Trng Res. Cent.*, Tech. Rep. 54–63.

Kurke, M. I., and McCain, C. N., Jr., 1957, Low power optical systems and aerial target detection. *U.S. Army Ord. Human Engng Lab.* Tech. Memo. 5–57, June.

Richardson, Bellows, Henry & Co., 1953, A study of the degree of illiteracy–literacy required in various naval battle stations. *Bur. Nav. Pers., Billet Qualif. Br.* Contract Nonr-416(00), July.

Roethlisberger, F. J., and Dixon, W. J., 1943, *Management and the worker* (Cambridge : Harvard Univ. Press).

Vince, M. A., 1953, The part played by intellectual processes in a sensorimotor performance. *Quart. J. exp. Psychol.*, **5**, 75–86.

MODERN TECHNIQUES FOR TIME AND MOTION STUDY IN PHYSIOLOGICAL RESEARCH

By H. S. Wolff

Division of Human Physiology, National Institute for Medical Research, Hampstead, London

Two methods are described by means of which time and motion study data from a number of subjects can be recorded and evaluated by a small and relatively untrained staff. The methods were originally devised for the purposes of energy expenditure surveys where continuous observations were required over periods of a week or more.

§ 1. Introduction

In recent years a number of metabolic surveys have been carried out on groups of people with the object of setting up a 24-hour metabolic balance sheet of food intake versus energy expenditure (Widdowson *et al.* 1954, Garry *et al.* 1955).

Whatever methods are used for the direct measurements of energy expenditure (e.g. Kofranyi and Michaelis 1940, Wolff 1958) there will always be periods when an instrument cannot be worn by the subject. During these periods the expenditure has to be calculated from independently measured or known values of energy expenditure for the activities concerned and from a time and motion study of these activities. By these means the total expenditure for a 24-hour period can be obtained.

There are other occasions when an exact knowledge of how the subject spends his day is useful—for example, as an insurance against failure of the method of direct measurement, or in order to compare the activities of two populations as a check on the validity of conclusions obtained from one population when applied to a second.

Groups of twelve Army recruits were studied for a week at a time in order to determine the calorie balance. Experience soon showed that conventional means for time and motion study recording by the use of stop-watch, pencil and paper were inadequate, even when the twelve men were treated as a single group. The main difficulty was the rapid change of activities encountered in military life and the complexity of some of the activities. There were three distinct situations, requiring different apparatus.

1. *Group study:* In this situation all twelve subjects behave as a group and can be studied as one man. The same method of study can be used if the subjects are engaged in a pattern of activities which, though identical for each man, is carried out by one subject following another. An example of the latter would be an activity such as jumping over a horse in the gymnasium which can only be done by one man at a time. In these circumstances one man is watched throughout but the results are applied to the group.

2. *Individual study:* The subjects act as individuals, each one engaged on his own task, but all within sight of one or a small number of observers.

3. *Diary form study :* The subject is not available for direct observation. Diary forms were first used extensively (Garry *et al.* 1955) during a survey of the food intake and energy expenditure of coal miners and clerks. The subject is supplied with a form divided into hours and further sub-divided into 1-minute squares in which he records his activities by means of a simple code. The method depends more than any other on the intelligence and cooperation of the subject; when these qualities are lacking, errors will be introduced. Evaluation of diary forms in quantity can be very tedious. Apparatus has been developed therefore to speed this evaluation.

The pieces of apparatus to be described are not original in their function; for example devices such as SETAR for recording time and motion study data have already been described (Welford 1952). However, in the present instance particular attention has been paid to making the instruments suitable for use in the field, often remote from a mains power supply, and for operation by persons who have had only the minimum of training.

§ 2. Methods

1. *Use of a radio link :* A big improvement in time and motion study technique was due to Adam (personal communication), who used observers carrying Walkie-Talkie radio sets. These observers watch the subjects, reporting every change of activity to a central laboratory. Even when pencil, paper and stop-watch are the means of recording, the method has the merit that the recordist is protected from inclement weather and can concentrate on reading his watch and writing down the time. With rapid changes of activity however the task of the recorder can be very difficult.

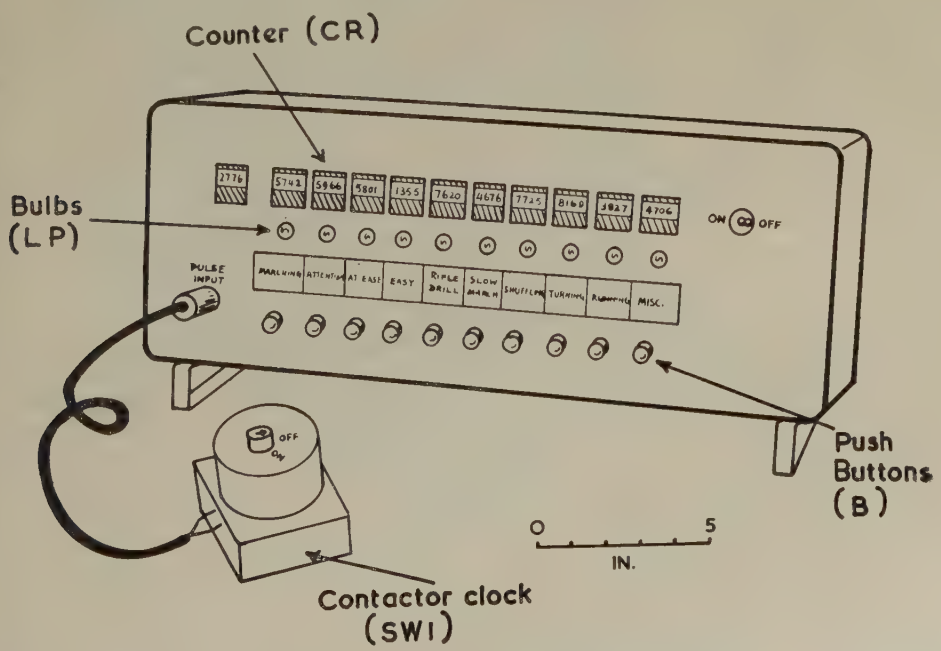


Figure 1. The multichannel integrating clock (MIC).

2. *Multichannel integrating clock (MIC)* : For ' group study ' a machine known as the multichannel integrating clock has been designed (Fig. 1). The front panel carries a row of Post Office counters, below that a row of bulbs, and finally a row of push buttons. On the left side of the panel a contactor clock can be plugged in. This feeds ½-second impulses into the machine. Depression of any button routes these pulses to the associated counter and lights the pilot bulb. As soon as another button is pressed the pulses are

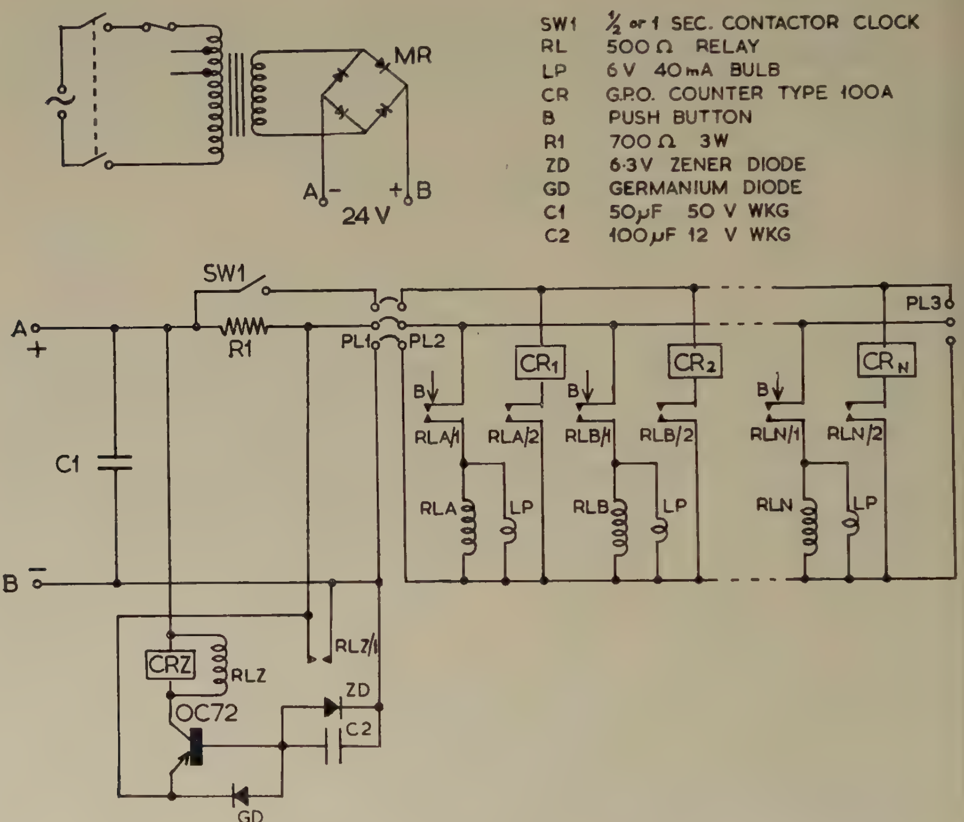


Figure 2. Circuit diagram of MIC.

The push buttons B bear directly on the armatures of the Post Office relays RLA–RLN. When, for instance, the button of RLA is depressed contact RLA/1 is made, the relay is energized and holds itself closed and the bulb is lit. At the same time RLA/2 is closed and counter CR_1 is energized at ½-second intervals due to the alternate opening and closing of SW_1 by the contactor clock. If another button is depressed, say RLB, the voltage drop across R_1 increases, because current is now flowing through two sets of relay coils and bulbs in parallel. This reduction in voltage causes the emitter of the OC72 transistor to become positive with respect to the base which is temporarily held at the original emitter voltage by C_2. The transistor conducts and starts to energize the counter CRZ and closes the relay RLZ. Contacts RLZ/1 close and short-circuit all the ' button relay coils ', and RLA opens, not being kept closed manually.

The closure of RLZ/1 makes the emitter of the transistor even more positive in relation to the base and sufficient current flows to operate the counter CRZ. Eventually C_2 discharges, RLZ/1 opens and RLB is energized and self-holds. Clock impulses are now routed to its counter until another button is depressed.

In this way the number of activity changes are counted on CRZ while the time in half-seconds spent on any component activity is registered on counters CR_1–CR_n.

routed to its particular counter. Between the bulbs and push buttons provision is made for the attachment of a strip of labels, assigning a component activity to each button and its corresponding counter. The machine is powered either from the a.c. mains or from a 24 v d.c. supply. Figure 2 shows the circuit diagram of the instrument.

The time spent on any component activity can be calculated if the counters are read before and after the period under study. The number of times a change occurs is also recorded on an additional counter. MIC is normally used in conjunction with an observer, carrying a Walkie-Talkie radio and reporting to the recordist.

If more than ten channels are required, one machine is left exactly as shown in the circuit diagram: the second machine has the connecting links between PL_1 and PL_2 removed. A lead is then connected between PL_3 of the first machine and PL_2 of the second. Further machines can be joined on, PL_2 of the additional machine always being connected to PL_3 of the previous machine.

3. *Evaluation of diary cards :* MIC can also be used for the evaluation of diary cards. The contactor clock is replaced either by a telephone dial or by the key-dialling device shown in Fig. 3. Both of these devices, when slightly

Figure 3. Post Office key dialling device used in conjunction with MIC for the evaluation of diary cards.

modified, can be made to open and close a contact a number of times equal to the number dialled (1–10). The appropriate button on MIC is depressed, the number is dialled, and that number is added to the corresponding counter. In practice, the operator starts at the beginning of the diary form, selects the first activity by pressing the appropriate button, dials a number corresponding to the duration of that activity and so continues throughout the from. The difference in counter readings before and after the evaluation of each form gives the time spent on each component activity.

4. *Punched card method for 'individual study' :* When the subjects being studied do not behave as a group, the MIC method becomes impracticable

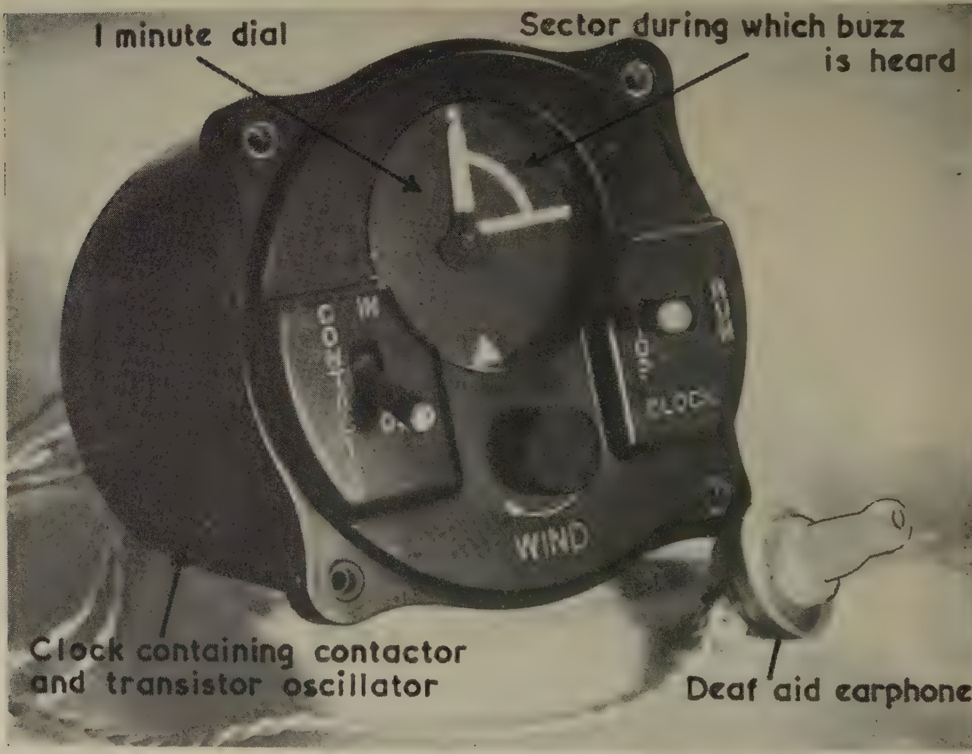


Figure 4. '1-minute' alarm clock.

because not only would it require one machine per subject but also an equal number of observers and operators. The 'punched card' method was designed to enable one recordist and one observer to study up to twelve subjects.

Subjects are observed at fixed time intervals and the activity at the moment of observation is recorded. This method, described as 'snap reading', was originally suggested by L. H. C. Tippett of the Shirley Institute (Tippett 1935); it has since then been renamed *activity sampling* in the British Standards Institution's Draft Specification defining terms for use in work study. Instruments for the semi-automatic recording and indication of the time intervals at which 'snap observations' are to be made have been described by

Kinniburgh and McTaggart (1954). Unfortunately their methods were not applicable to a study involving both a large number of subjects (up to 12) and a relatively large number of different activities (up to 11). The present method using punched cards for data storage was therefore developed.

The observer is trained to announce over a radio link the activities of his subjects at 1-minute intervals, the order of observation of the subjects always being the same. To assist him to keep accurately to 1-minute intervals without reference to his watch, he is provided with a 1-minute alarm clock which produces a buzz, for 15 seconds of every minute, in a deaf-aid earphone worn in one ear (Fig. 4).

The recordist is provided with a Powers-Samas 21-column hand punch (Fig. 5) and a supply of cards (Fig. 6). A card is inserted into the punch and the carriage pushed home so that the operation of any key will punch a hole in column 1. There are eleven keys, each of which can punch a hole in any one of eleven positions within each column (the eleventh position is above the 0). Each key is labelled with a component activity. After a key has been depressed the carriage moves on by one column so that successive depression of the keys will punch holes into successive columns.

As the activity information from the observers is always received in the same order of subjects, the number of the column corresponds to the subject and the position of the hole within the column defines the activity at the moment of observation. One card is produced for every minute. A code can be punched into the last two columns of each card to indicate the day of the experiment and the period during the day. The purpose of the 15-second buzz in the observer's alarm clock is to give the recordist a chance to remove the punched card from the punch and to insert a fresh one.

At the end of the survey the cards are analysed by a Powers-Samas card sorting machine which can be set to analyse at any one time any column on the card. When the cards pass through the sorter they are divided into eleven packs according to the position of the punched hole and the number in each pack is indicated. This number is equal to the number of minutes the particular subject spent on the component activity corresponding to the position of the hole. If there is no hole the card is rejected. The analysis is continued column by column until the information for each subject has been extracted. The sorting machine can handle cards at the rate of 36 000 per hour, so that the time taken to insert and remove packs of cards and to write down the counts is the factor limiting the speed of analysis.

If all the subjects are close to the observer it is possible for him to do his own recording, using the 1-minute alarm clock to space his observations. It takes one or two days to train an observer to recognise his subjects rapidly especially in unusual positions and at a distance. The hand-punch operator soon learns to touch-type, and can then record the activities of as many as twelve subjects within 1 minute with time to spare.

Eleven activities were not sufficient to cover all aspects of army life; three punches were therefore used, having different selections of activities on their keys and using cards of different colours. At the beginning of a recording period the most appropriate punch was selected.

By an elaboration of the punched-card method it is also possible to record the number of times the component activity changes. The card which refers

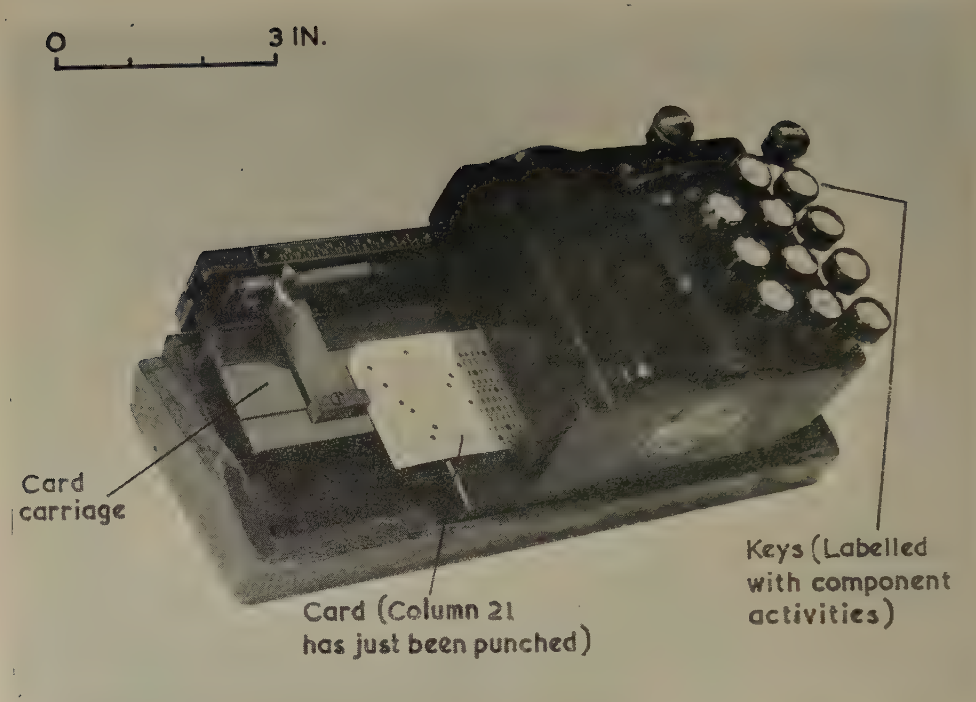


Figure 5. Powers-Samas 21 column hand-punch with card in position.

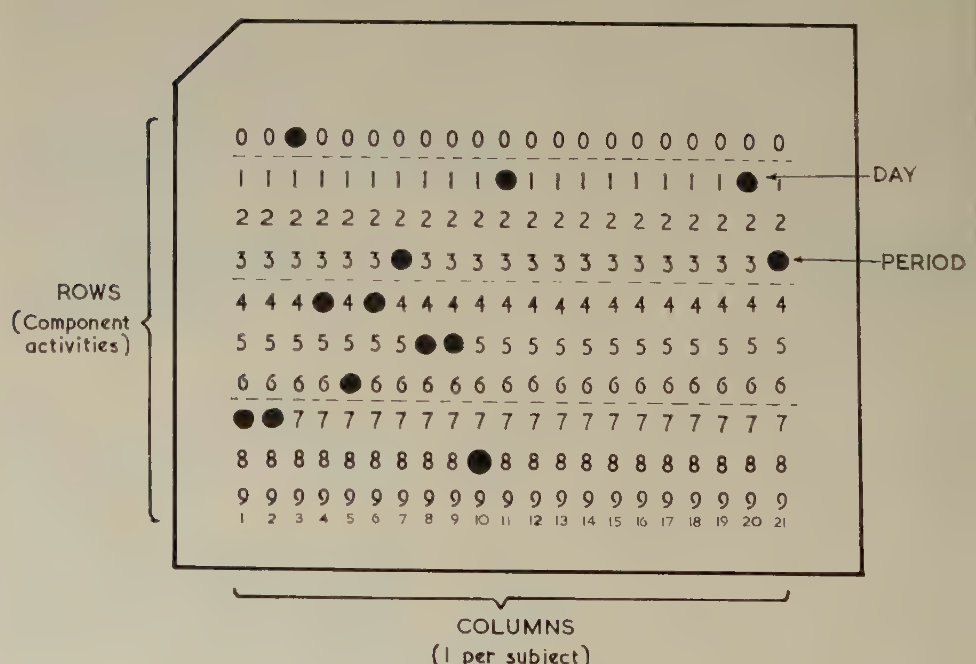


Figure 6. Twenty-one column Powers-Samas card. The holes in columns 1–11 represent the activities of 11 subjects; the holes in columns 20 and 21 are the day and period code.

to minute 'n' is reinserted into the punch with a second blank card on top of it, and minute $n+1$ is then punched. If there has been no change of component activity the punch will pass through the same hole again in card n. If there has been a change, a second hole will appear in a column in the bottom card. This procedure is followed throughout the whole period, each card remaining in the punch for two successive minutes.

During the sorting operation the sorter will only take note of the lower number in columns where there are two holes. The sorter can be made to search for higher numbered holes by putting in the pack from, say, No. 2 compartment, closing a cover over the compartment so that cards cannot fall into it, and repeating the sorting operation. Cards without a second hole will be rejected, while those with a second hole will be put into the appropriate compartment. In this manner, by sorting all packs from compartments 0 to 10 a second time, all the cards with two holes in one column can be found. The total number so found is equal to the number of changes of component activity. This double sorting has to be carried out for as many columns as there are subjects*.

Because of double punching there are more holes than minutes, each change of component activity having produced an extra hole. There is no means of telling which hole was there first and refers to the minute appropriate to the card; moreover, the second hole only denotes that there has been a change and occurs again in the subsequent card. Fortunately, in any period of recording, an activity must have been changed 'to' as often as 'from', with a maximum possible error of 1. If $A_1, A_2 \ldots A_x$ be the numbers of cards with only one hole, in positions 1, 2, ... x, and if $B_1, B_2 \ldots B_x$ be the numbers of cards with two holes, the suffixes representing the punchings as before, then: numbers of minutes spent on activity $x = A_x + \frac{1}{2}B_x \pm 1$.

Additional information is also available about the frequency of change between pairs of component activities.

§ 3. Discussion

The methods which have been described allow a small staff of relatively untrained technicians to carry out a time and motion study on a number of subjects over long periods of time. The information is presented in a form which allows easy evaluation. The use of a radio link means that the observer can remain in close touch with his subjects.

When data obtained by these means are used to calculate energy expenditure, it has been found that the calculated value is, in general, lower than the measured value obtained at the same time (Fletcher 1958). It is suggested that the deficiency may lie in the energy expended in the changes of component activity which are often associated with changes of posture or with acceleration or deceleration of the whole or part of the body. For these changes no allowance is made in the simple time and motion study technique described. It is for this reason that arrangements were made, in the two methods described, to count changes of component activity.

* For the purposes of description the method of operation of the sorter has been simplified; it does not necessarily represent the actual sequence of events on the machine. It is possible, however, to achieve the results indicated.

L'article décrit deux méthodes permettant l'enregistrement et l'estimation par une équipe réduite et relativement peu entraînée de données d'étude des temps et mouvements relevées sur plusieurs sujets. Les méthodes ont été mises au point initialement pour l'étude de la dépense énergétique au cours d'observations continues durant une semaine ou plus.

Es werden 2 Methoden beschrieben, mit denen die Werte von Zeit- und Bewegungsstudien an einer Anzahl von Personen mit einem relativ kleinen und ungeübten Stab von Untersuchern aufgenommen und ausgewertet werden können. Die Methoden wurden ursprünglich für Energieumsatz-Untersuchungen entwickelt, bei denen fortlaufende Beobachtungen über eine Woche und länger notwendig waren.

References

Fletcher, J. G., 1958, *Daily energy expenditure in young men*, pp. 125–127. Ph.D. Thesis, University of London.

Garry, R. C., Passmore, R., Warnock, Grace M., and Durnin, J. V. G. A., 1955, Studies on expenditure of energy and consumption of food by miners and clerks, Fife, Scotland, 1952. *Spec. Rep. Ser. med. Res. Coun., Lond.*, No. 289 (London: H.M. Stationery Office).

Kinniburgh, W., and McTaggart, G., 1954, Snap observation helps time study in building. *The Manager*, March 1954, 179–182.

Kofranyi, E., and Michaelis, H. F., 1940, Ein tragbarer Apparat zur Bestimmung des Gastoffwechsels. *Arbeitsphysiologie*, **11**, 148–150.

Tippett, L. H. C., 1935, Statistical methods in textile research. III. A snap reading method of making time studies of machine operatives in a factory survey. *J. Text. Inst.*, **26**, 51–70.

Welford, N. T., 1952, An electronic digital recording machine—the SETAR. *J. sci. Instrum.*, **29**, 1–4.

Widdowson, Elsie M., Edholm, O. G., and McCance, R. A., 1954, The food intake and energy expenditure of cadets in training. *Brit. J. Nutr.*, **8**, 147–155.

Wolff, H. S., 1958, The integrating motor pneumotachograph: a new instrument for the measurement of energy expenditure by indirect calorimetry. *Quart. J. exp. Physiol.*, **43**, 270–283.

BEHAVIOUR IN CONTROLLING A COMBINATION OF SYSTEMS

II. Effects of Changes in the Velocity of Disturbances*

By K. F. Jackson

Institute of Aviation Medicine, Royal Air Force, Farnborough, Hampshire

In a multiple tracking task the operator has considerable freedom to choose his own rate of working. An experiment is described in which the velocity of disturbances influencing such a task is shown to affect this choice.

'Speed stress' has usually been discussed in the context of paced tasks (Conrad 1951). Presumably the word 'stress' is used here to denote a condition which has direct effect on behaviour such as to impair performance. Thus excessive speed of a conveyor belt bringing components for assembly could be an example of speed stress, because it could deprive operators of the opportunity to work at their most effective individual rates.

In continuous tracking tasks speed is also an important variable, but in this case the word 'stress' is inappropriate. If for example a dial carries a pointer having a tendency to deviate, and the task is to maintain alignment of the pointer with a fixed mark, the velocity of the disturbances which give rise to the deviations does not necessarily affect the behaviour of a person controlling the system. He can order his activities with far more independence of the sequence of external events than the conveyor belt operator can. On the other hand, if the person controlling a dial does not respond to changes in the velocity of the disturbance, the *overall results* as opposed to the corrective actions he makes are indeed dependent upon the velocity of the disturbances because the human operator acts as an intermittent correction servo (Craik 1948, Vince 1948). In a multiple tracking task where several systems have to be controlled by one operator, the dependence of overall results upon velocity may be even greater, because here the operator works in a state of enforced intermittency of a severity dependent upon the number of systems involved.

In a previous article (Jackson 1958) a simplified mathematical model of such a situation was described and an account was given of an investigation of the consequences of varying the number of systems to be controlled.

The object of the experiment to be described here was to determine the effect upon the pattern of operator behaviour of uniform variation in the velocity of disturbances affecting a set of four dials.

§ 1. Apparatus and Method

The equipment used was the multiple tracking task described in the previous article. This was provided with four dials controllable by four knobs. Disturbances were fed into the system by a set of cams which could be rotated together at any desired speed. Facilities were available for measuring a number of aspects of response behaviour as well as the overall results of performance.

The subjects were instructed to work systematically round the set of dials, giving them equal attention, and to try to keep the pointers as near to zero as

* This article is based on part of a Ph.D. thesis approved by the University of London.

possible all the time. After practice the twelve subjects were tested individually for three minutes in each of three conditions of disturbance velocity in which the cams were set to rotate at 0·6, 1·0, or 2·0 cycles per minute respectively. The conditions were presented in a balanced series of orders.

1.1. *Measurement of Performance*

The total amount of time (T_c) spent in manipulating the control knobs was measured, and by dividing the number of control movements (m) made during a trial the average duration of a control movement (t_c) was obtained. The average duration of the periods of interruption in the continuity of control of any one system (t_i) was calculated from the formula $t_i = (nT - T_c)/m$. n being the number of control systems (4) contributing to T_c, and T being the total duration of a trial (180 sec).

The integrated modulus error was measured for each individual system in two parts, for the periods of interruption and control separately. By dividing the integrated errors by $mt_i/4$ and $T_c/4$ respectively, the modulus mean errors for interruptions (E_i) and control movements (E_c) were derived.

The average distance through which the pointers moved during the interruptions was estimated by multiplying the average speed of pointer movement produced by a given speed of cam rotation by t_i. This is equivalent to the average amplitude of a correction made by the operator, assuming that he keeps each system in a steady state of equilibrium. An estimate of the average speed of control movements was made by dividing the amplitude of the control movements by their duration (t_c).

The average duration of movements of the hand (t_m) in changing over from one control knob to another was found by the formula $t_m = (T - T_c)/m$.

It was shown in the previous article that the amount of integrated modulus error built up during a given interruption depends upon the position of the pointer at the beginning of the interruption. This relationship was used to estimate the beginning points of pointer excursions and hence the extent to which under or over-corrections were made by the operator and the average size of errors built up during the interruptions.

§ 2. Results

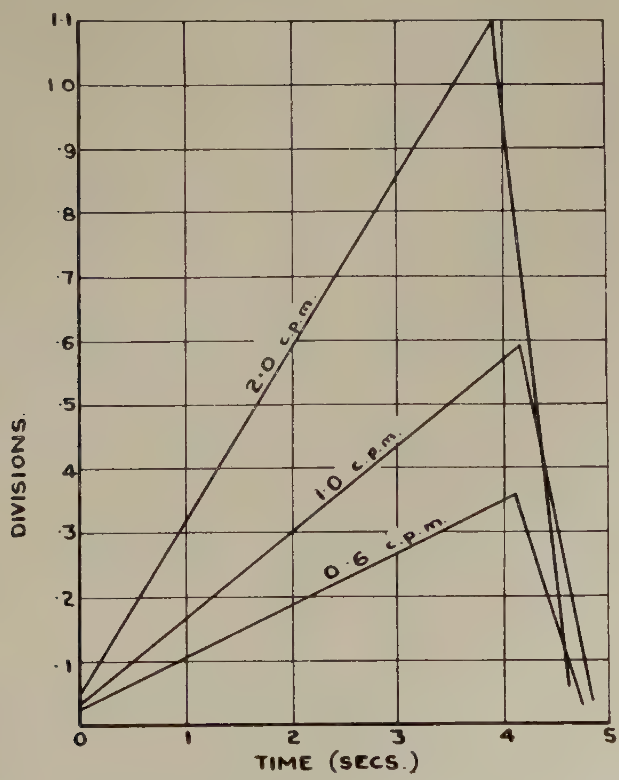
The table shows the means and standard errors of individual results for the six major parameters of performance. Analysis of variance showed that only the modulus mean errors were significantly affected by changes in the velocity of disturbance.

The changes of velocity affected neither the rate of working as a whole nor the components of this overall rate, namely, duration of control movements and duration of change-over movements The duration of interruptions, being dependent upon these components, was similarly unaffected. In consequence of this lack of change in the amount of time devoted to the various events, the errors built up during interruptions and the amplitude and speed of control movements followed the changes in disturbance velocity almost exactly.

The errors which built up during the interruptions were actually slightly greater than the corrections made, because there was a preponderance of under-correction in the subjects' responses. Over-corrections tending to anticipate

Means and standard errors of the main measures of performance

Measure	Velocity of disturbance in terms of revolutions per minute of the cams					
	0·6		1·0		2·0	
	Mean	S.E.	Mean	S.E.	Mean	S.E.
Rate of working (in movements per trial) (m)	150·67	17·85	151·75	18·39	154·75	14·62
Amount of time spent in manipulating control knobs (in sec) (T_c)	108·83	4·97	100·08	4·97	100·66	4·51
Duration of control movements (in sec) (t_c)	0·708	0·087	0·783	0·110	0·801	0·098
Duration of interruptions (in sec) (t_i)	4·086	0·411	4·023	0·381	3·790	0·319
Modulus mean error for control movements (in scale-divisions per dial) (E_c)	0·134	0·009	0·181	0·015	0·272	0·021
Modulus mean error for interruptions (in scale-divisions per dial) (E_i)	0·168	0·013	0·265	0·024	0·497	0·018



Changes in control equilibrium with increasing velocity of disturbance.

the coming disturbances were not apparent in these results. The small residual errors that were made, increased with higher velocities of disturbance.

The figure is an idealized combined diagram showing the interrelations of the foregoing results.

§ 3. Discussion

It was noticeable in the comments of the subjects that variation in velocity of disturbance, even of the magnitude used in this experiment, is not clearly perceived. A number of subjects were not sure whether the speed had varied or not. Perhaps this is the reason why subjects did not alter their overall rate of working (in terms of the number of corrective movements they made per trial) in keeping with the changes in the velocity of disturbance. This is in contrast to the previous experiment (Jackson 1958), where changes in the *complexity* of the task (in terms of number of dials) were perfectly obvious.

In this experiment the subjects did little to compensate for the additional difficulty of the task. They did not significantly speed up their change-over movements, and their control movements although faster with greater disturbance velocity were not shortened in duration. As in the previous experiment, the error built up during the interruptions was proportional to the independent variable (velocity of disturbance in this case), but not so precisely as it was with variation in the number of dials. The only major effect upon operator behaviour of increases in the velocity of disturbance was that the speed of control movements rose, on average, proportionally to the velocity of disturbance and hence proportionally to the errors that had to be dealt with. Over-corrections tending to anticipate coming disturbances were uncommon but the under-correction followed the trend found in the previous experiment of being less adaptive in the more difficult tasks.

Taking the results of the two experiments together, it appears that when faced with changes in the difficulty of his task due either to increased load (number of channels to be dealt with) or increased velocity of disturbance, the operator adapts his responses considerably. The more difficult the task, the worse state he is prepared to let it get into, but at the same time the more difficult the task the faster he is prepared to make his control responses. A compromise tends to be struck between these two principles, which in the situations described is sufficient to determine the overall pattern of his performance, there being no further degrees of freedom.

Une tâche de poursuite multiple laisse à l'opérateur une grande latitude dans le choix de son régime propre de travail. L'expérience montre que la rapidité des changements se produisant dans cette tâche affecte son choix.

In einer vielfältigen Folge-Bewegungs-Aufgabe hat der Arbeiter grosse Freiheit, seine eigene Arbeitsgeschwindigkeit zu wählen. Diese Wahl wird—wie in einem Experiment gezeigt wurde—durch die Geschwindigkeit eintretender Störungen der Aufgabe beeinflusst.

References

Conrad, R., 1951, Speed and load stress in a sensori-motor skill. *Brit. J. industr. Med.*, **8**, 1–7.

Craik, K. J. W., 1948, Theory of the human operator in control systems. II. Man as an element in a control system. *Brit. J. Psychol.*, **38**, 142–148.

Jackson, K. F., 1958, Behaviour in controlling a combination of systems. *Ergonomics*, **2**, 52–62.

Vince, M. A., 1948, The intermittency of control movements and the psychological refractory period. *Brit. J. Psychol.*, **38**, 149–157.

THE EFFECT OF A SHORT REST-PAUSE ON INSPECTION EFFICIENCY

By W. P. Colquhoun

Medical Research Council, Applied Psychology Research Unit, Cambridge

Little is known about the efficiency of inspectors engaged on simple checking work, or whether short rest-pauses are beneficial to performance at such tasks. An experiment was carried out to investigate these questions in the case of machine-paced work. The results showed that, when the work was uninterrupted for a period of one hour, efficiency, although high on average, declined markedly after about thirty minutes. When a rest-pause of five minutes was inserted at this point, performance was maintained at its initial level throughout the hour. The theoretical and practical significance of these findings is discussed.

§ 1. Introduction

Quality of product in most industrial processes is normally maintained by means of inspections at various stages of manufacture. Certain of these inspections may be intended to provide no more than a simple check on the incidence of specified defects in the material. The work involved in making simple checks of this kind requires little skill, and is frequently carried out at a very fast rate. It is not uncommon for checking to continue for periods of two or three hours at a stretch without an ‘ official ’ rest-pause. However, although the flow of work may appear continuous, in the majority of factories the time spent over the examination of individual items, or of particular parts of the material, can vary within quite wide limits, and this enables the inspector to take occasional brief rests during what might otherwise be an unbroken session of checking. In practice, sessions are usually interrupted at intervals for periods during which work of a different kind is required. The frequency and duration of temporary changes in activity vary widely in different inspection departments, but it is only rarely that checking work is performed for lengthy periods of time without interruption, or that the task is machine-paced to such an extent that even brief rests are impossible.

Although in the future, many parts of the production process are likely to benefit from the application of recently developed automatic techniques, it appears likely that for technical or economic reasons automatic inspection will not be possible in most industries for some years to come. Human observers will therefore still be needed in many cases to discriminate ‘ rejects ’ from satisfactory products. These inspectors may be required to work at high speed in order to keep pace with the output from automatic manufacturing machinery. In these circumstances even the shortest lapse in attention on the part of a checker who is unable to look twice at any article could result in a faulty item being passed to the next stage in the process.

It is clear that it will not be possible to take ‘ unofficial ’ rests in this kind of inspection work, which Mackworth (1956) discusses as an example of what are termed ‘ vigilance ’ tasks. Behaviour in these tasks has been extensively studied in recent years. The experimental work has been reviewed by Broadbent (1958), and Colquhoun (1957) has discussed the extent to which the findings are relevant to industrial inspection work. One of the more

obvious ways in which many inspection jobs differ from the tasks which have been used in experimental studies of vigilance is the far greater number of 'signals' occurring in a given time in real inspection work. But since, in most cases, only a small proportion of the inspected material is in fact faulty, most of these signals are 'unwanted' in the sense that no positive response to them is required.

It has been shown that signal detection in vigilance tasks is materially assisted by the introduction of a rest-period of half an hour (Mackworth 1950), or even of ten minutes only (Adams 1956). Would efficiency at the somewhat different sort of work involved in inspection also improve if short controlled breaks were provided? No direct research appears to have been carried out on this question, but it is interesting to note that, in several inspection operations observed by Belbin (1957), the viewers felt the need to take a rest-break, or, alternatively, to change to some different sort of work, at intervals which in some cases were as short as fifteen minutes. No factual evidence was available, however, as to the relative efficiency of these viewers when breaks were taken or omitted. The present experiment was undertaken to obtain such evidence in the case of simple machine-paced checking work.

§ 2. Apparatus and Method

The task used in the investigation was designed to simulate industrial situations in which inspected articles are transported past the examining stations on a conveyor belt, and the time-limit for detecting and rejecting faulty material is short.

A large drum, carrying one hundred $5\frac{1}{4}$ in. $\times$ $\frac{3}{4}$ in. metal strips equally spaced around its circumference, presented the subjects with a flow of 'objects' for inspection. Six objects were mounted on each strip, with $\frac{7}{8}$ in. between centres. The drum was enclosed in a cover in which an aperture allowed one strip to be observed at a time. The output from a variable-speed motor rotated the drum, at regular intervals, through one-hundredth of its diameter, presenting the strips sequentially at the viewing aperture. The exposed strip was displayed with its face inclined at an angle of 40° to the vertical, and was positioned 24 in. from the seated subject, some 15 in. below the level of his eyes. Illumination was provided by a 60 watt bulb on either side of the viewing aperture, immediately below which six response keys were placed so as to be directly in line with the set of six objects on each strip.

The 'objects' in this experiment were photographic prints of a disc, $\frac{1}{4}$ in. in diameter, showing as off-white on a dark grey background to give a moderately high degree of contrast. Of the 600 discs on the drum 72 (12 per cent) were 'faulty', in that they were marked by a small black spot 3/64 in. in from the edge. Each spot was assigned, at random, an angular position on the disc of 30°, 60°, 90° or 180°. Faulty discs appeared on 68 of the strips. On 64 of these only one disc was faulty; the remaining four strips had two faulty discs placed on them in order to ensure that subjects did not cease to search for faults on a strip as soon as they had found one. The faulty discs were arranged on the strips so that they appeared in each of the six possible positions with equal frequency. The order in which the strips were displayed at the aperture was one found empirically to minimize the likelihood of recognition of parts of the sequence when this was repeated a number of times.

The subject's task was to inspect each set of six objects as it appeared, and to press the key under any disc which carried a spot, before the drum removed the set from view and replaced it with another. Failure to respond in the alloted time to a strip carrying a faulty disc was recorded automatically on an electro-mechanical counter. After each complete rotation of the drum, the total number of response failures was noted by the experimenter (failures to respond to both faults when two occurred on one strip were not included in this total). 'Late' responses to strips, made while the display was changing, were not recorded.

The motor speed was set so that 50 strips (300 discs) were presented per minute, giving, when changeover time is deducted, a viewing period for each strip of approximately one second. Test sessions lasted for one hour, during which the entire sequence of one hundred strips was displayed thirty times. The experimenter remained in the room during the tests, but he was screened from the subject and did not communicate with him in any way.

Thirty-two young naval ratings served as subjects. All had normal or corrected vision. The task was explained to each subject when he arrived at the test-room. He was told to try not to miss any 'faults' (spotted discs), and to respond to a fault by pressing the appropriate response key as quickly as possible. It was emphasized that responding 'late' (when the drum was rotating) would count as a 'miss'. Five minutes practice was given, after which the subject was told to carry on inspecting for 'about an hour'. Half the subjects (chosen at random) were informed that they would have a break 'half-way'. These subjects were given a rest of five minutes duration after thirty minutes of testing. During the rest-period subjects were allowed to talk, smoke, or walk about as preferred. Half the subjects in both the 'rest' and 'no rest' groups started work at 10.00 a.m.; the remainder started at 2.00 p.m.

§ 3. Results

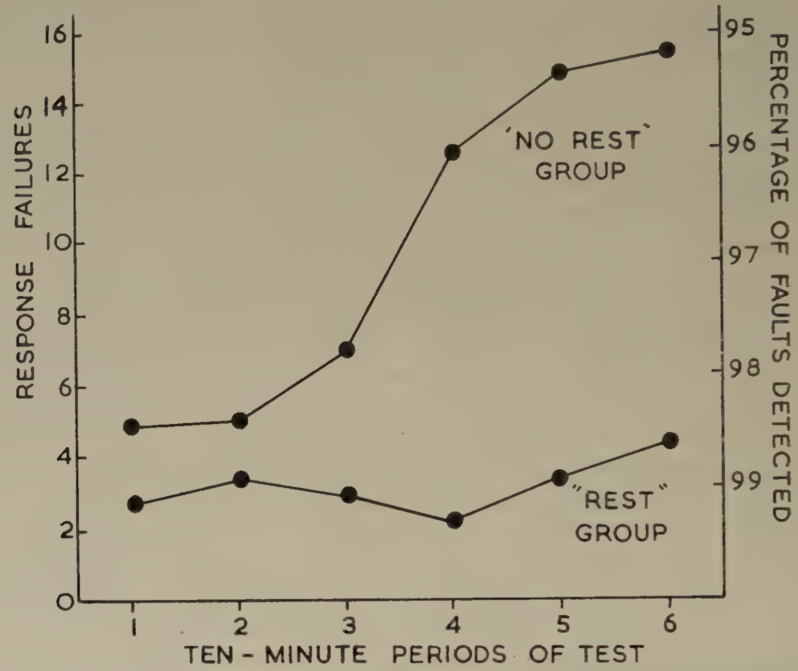
The average number of response failures in each successive ten-minute period on the task is shown in the figure for the 'rest' and 'no-rest' groups of subjects. A derived measure of inspection efficiency (the proportion of faults to which a response was made) is also indicated. It can be seen that although the general level of performance during the test was high in both groups, the efficiency of the 'no-rest' subjects deteriorated markedly during the second half-hour. The number of responses omitted by the 'rest' group, on the other hand, remained small throughout the test.

In order to assess the significance of the differences between the groups, total response failures for each subject in each half-hour of the test were obtained. The means and ranges of these half-hour totals are given in the table.

A square root transformation was carried out on these scores to normalize the distribution. Analysis of variance of the transformed scores for the first half-hour showed that the population difference, if any, between the 'rest' and 'no-rest' groups in this period is too small to be found significant by an experiment of this size. In other words, it cannot be said that the knowledge of a rest-pause to come had any effect on performance during the first half-hour.

Second half-hour scores were adjusted, before analysis, for their regression on the corresponding first half-hour values.

The analysis of these adjusted scores showed that the probability, by chance alone, of obtaining (in repeated experiments using different subjects) a difference between the ' rest ' and ' no-rest ' groups as large as the observed difference is less than 0·05, indicating that the rest-pause had a genuine effect on efficiency in the period that followed it.



Mean response failures for ' rest ' and ' no rest ' groups in successive ten-minute periods of testing time.

Means and ranges of half-hour totals of response failures

	' Rest ' group		' No rest ' group	
	1st half hour	2nd half hour	1st half hour	2nd half hour
Mean	9·4	9·9	17·6	44·1
Range	1–29	1–37	0–89	0–295

The considerable differences in individual checking efficiency that were observed were found to be unrelated either to intelligence as measured by Heim's test A.H.4, or to temperament as indicated by subjects' scores on Part I (emotional instability) and Part II (unsociability) of the Heron test (Heron 1956).

§ 4. Discussion

The average level of efficiency throughout the session was much higher, in both the ' rest ' and ' no-rest ' groups of subjects, than the usual levels observed during sessions of similar length in experiments on vigilance. This may mean simply that the discrimination of faults in the checking task is less difficult than is, for example, the detection of target echoes on a radar display; but it is possible that the high rate of signal presentation was in part responsible for

the superior standard of performance. It is true that average efficiency in the Clock Test (Mackworth 1950), in which signals were presented at the same rate as in the present case, was not high; but the proportion of signals in that task which was ' wanted ' was less than one per cent, whereas in the checking work, 68 of every 100 strips were faulty. Jenkins' (1953) finding that detection efficiency in a vigilance task is closely related to the frequency with which *wanted* signals are presented to the subject suggests that the high proportion of faulty strips was the important factor in the present case.

The results for the ' no-rest ' group show that when performance was uninterrupted, efficiency declined with time in much the way that detection ability did in Mackworth's Clock Test. Mackworth also observed, however, that during the second half-hour of an hour's watch there were twice as many slow reactions to detected signals as there were in the first half-hour. No time-limit was imposed on responses in Mackworth's experiments, but since in the present study only one second was allowed, it is possible that the increase in response failures recorded in the latter part of the session was brought about as much by a rise in the incidence of slow reactions to observed faults as by a greater liability to miss the faults altogether. Further experiments with the checking task in which no time-limit is imposed on responses would be necessary to settle this point.

Missed faults, and slow reactions, could both be caused by perceptual ' blocks ' (Bills 1931), during which the perceptual system would effectively be closed to the relevant stimuli in the viewing aperture. Since it appears that blocks of this nature may last for a period of rather more than one second (Broadbent *op. cit.*), any faults on a strip would almost certainly be missed if the onset of a block coincided with the beginning of a viewing period. If a block occurred before scanning of a particular strip was completed, a fault appearing in the unscanned position would also stand a high chance of escaping detection. However, a fault in the following strip might, despite the reduction in viewing-time imposed by the block, still be detected successfully, but not in time to allow a response to be completed. In these circumstances the response might be inhibited by the subject, or alternatively, be carried through but fail to be recorded because the display was changing again at the time.

The effects of blocking could presumably be eliminated by increasing the viewing time for each strip. In the practical case a reduction in the rate of flow of material past the inspection point would achieve the same object. However, the results for the ' rest ' group demonstrate that such a course, involving, as it would, a reduced work output, may not be necessary if steps are taken to alter the conditions which are responsible for the increased frequency of blocks after a period of work. The outstanding characteristic of paced inspection work is its unrelieved monotony, both qualitative and temporal, and it is known that monotonous conditions like these are conducive to an increase in the blocking rate after a time. The results of the present experiment suggest that a short rest-pause provides a degree of variation in the pattern of stimulation which is sufficient to prevent this increase.

The general behaviour of subjects during the test provided an additional source of information on the effects of the task conditions. When the task was performed without a break being given, the restlessness of subjects in the second half-hour, and the frequency with which they yawned, hummed tunes,

and commented on the work to themselves suggested that they were finding the job irksome during this period; and in fact, the majority of these subjects, when interviewed afterwards, reported having experienced moderate or pronounced feelings of boredom during the later stages of the test. Such comments were rare from members of the ' rest ' group, and objective signs of ' fatigue ' were not observed in most of these subjects during the session. When a rest was not given, most subjects stated that they would have performed better if one had been allowed.

Since the present investigation was limited to a single hour's observation on each subject, it is not possible to say whether rest-breaks of five minutes duration taken at thirty-minute intervals would maintain efficiency at its initial level during the several hour's work that would be required of an inspector in a real industrial situation. Again, it is not known whether a regular cycle of work–rest–work would not itself become monotonous when repeated for days or weeks on end. The answers to these questions can only come from carefully controlled field research, the need for which becomes increasingly urgent as the sort of work studied in the present investigation replaces the traditional skills of a pre-automation age.

Acknowledgments are due to Dr. Mackworth, who directed this work, to Dr. Stone for statistical advice, and to the Royal Navy who supplied the subjects. Financial support was provided by the Medical Research Council.

On connaît peu de chose sur l'efficience des contrôleurs occupés à un travail de contrôle simple et on ne sait pas non plus si de courtes pauses sont favorables à l'accomplissement de ces sortes de tâche. Cette expérimentation a pour but d'examiner ces questions dans le cas d'une tâche à allure imposée par la machine. Les résultats montrent que le travail poursuivi sans arrêt pendant une heure s'accompagne après 30 minutes environ d'une diminution sensible de l'efficience, bien qu'en moyenne celle-ci soit élevée. L'introduction d'une pause de 5 minutes à ce moment-là maintient le niveau de la performance à sa valeur initiale durant toute l'heure. La discussion porte sur la signification théorique et pratique de ces constatations.

Es ist wenig über die Leistungsgüte von Prüfern bekannt, die mit einfachen Kontrollaufgaben betraut sind. Sind kurze Restpausen für die Durchführung solcher Kontrollen günstig ? Zur Untersuchung dieser Frage wurde bei maschinen-gesteuerter Arbeit ein Experiment durchgeführt. Die Ergebnisse zeigten, dass die Leistung, wenn die Arbeit ununterbrochen während einer Zeitspanne von 1 Stunde lief, nach ungefähr 30 min merklich abnahm, obgleich sie durchschnittlich hoch lag. Wurde nach 5 min Ruhepause eingeschoben, so blieb die Leistung während der ganzen Stunde auf dem Anfangsniveau. Die theoretische und praktische Bedeutung dieser Befunde wurde diskutiert.

References

Adams, J. A., 1956, Vigilance in the detection of low-intensity visual stimuli. *J. exp. Psychol.*, **52**, 204–208.

Belbin, R. M., 1957, Compensating rest allowances. *Work Study and Industrial Engineering*, December.

Bills, A. G., 1931, Blocking: a new principle in mental fatigue. *Amer. J. Psychol.*, **43**, 230–245.

Broadbent, D. E., 1958, *Perception and Communication* (London: Pergamon Press).

Colquhoun, W. P., 1957, Vigilance and the inspection problem. *Personn. Mgmt*, **39**, 163–171.

Heron, A., 1956, A two-part personality measure for use as a research criterion. *Brit. J. Psychol.*, **47**, 243–251.

Jenkins, H. M., 1953, Performance on a visual monitoring task as a function of the rate at which signals occur. *M.I.T. Lincoln. Lab. tech. Rep.* 47.

Mackworth, N. H., 1950, Researches on the measurement of human performance. *Medical Research Council, Special Report Series* No. 268 (London: H.M.S.O.); 1956, Work design and training for future industrial skills. *J. Instn Prod. Engrs*, **35**, 214–240.

REST PAUSES IN A TASK AFFECTED BY LACK OF SLEEP

By R. T. Wilkinson

Medical Research Council, Applied Psychology Research Unit, Cambridge, England

It has been confirmed that 30 hours' loss of sleep can seriously impair performance towards the end of a 25-min test of serial reaction. In particular, the occurrence of gaps, or abnormally long response delays, is greatly increased. This is what happens when the test is a continuous one; when 30-sec rest pauses were allowed every 5 min this effect of lack of sleep was found to remain unaltered, an equal though small and insignificant improvement in performance occurring under both normal and sleep-deprived conditions.

§ 1. Introduction

Patrick and Gilbert (1896) carried out one of the first experiments on lack of sleep and found that a test involving repetitive serial reaction showed more effect than most. In their task the subject was presented with a succession of stimuli, for example, 1000 randomly arranged letters of the alphabet. He had to respond appropriately to each letter in turn by naming it as quickly as possible.

This finding has been confirmed in subsequent studies, but only once at a satisfactory level of significance. Kleitman (1923) found speed of colour naming affected by lack of sleep in a 15-min test but not in one lasting only 5 min; but he used only one subject. A study by Warren and Clarke (1937) suggested that the incidence of long intervals between responses, 'blocks' as defined by Bills (1931), was increased by lack of sleep, and Bjerner (1949) associated these blocks with periods of alpha depression in the EEG record. Finally Pepler (1958), in consultation with the present author and using the same system of sleep deprivation, showed that speed was reduced and blocks increased significantly as a result of one night's loss of sleep; he used the Five Choice Test, a serial reaction task developed by Leonard (1959).

The present experiment used the same test and was designed, firstly, to check Pepler's result and, secondly, to discover whether lack of sleep would have less effect if rest pauses were given periodically.

§ 2. Procedure

The Five Choice Test has been described a number of times both as regards apparatus (Leonard 1959), and procedure (Pepler 1958, Wilkinson 1957, 1958), so that only a brief outline need be given here. The subject sits before a horizontal board 18 in. square; inset flush with the surface of this are five brass discs $1\frac{1}{2}$ in. in diameter so placed that they would lie one at each angle of a regular pentagon having sides of length $3\frac{1}{2}$ in. Against each disc a bulb is inset in the board face and at the outset of the test one of these bulbs is alight. Using a stylus the subject taps the associated disc, whereupon the bulb goes out and one of the others lights up; again the associated disc is tapped and the light moves on. The task is to go on tapping in this way as quickly and as accurately as possible. The order in which the bulbs light up over successive

taps is pre-arranged to appear random, but in fact the sequence repeats every 100 taps. When the wrong disc is tapped (e.g. one whose bulb is not alight) the light still moves on and an *Error* is counted; otherwise a *Correct* is counted for each correct tap. In addition a *Gap* is scored every time the subject allows a period of $1\frac{1}{2}$ sec or more to elapse between successive taps. These *Gaps*, it should be mentioned, are thought of as being essentially the same as the blocks scored by Bills; the difference is that for a *Gap* to be scored the reponse interval must exceed $1\frac{1}{2}$ sec, whereas for the block it has to be more than twice the prevailing average interval.

The subject continued tapping for 25 min and scores of *Corrects*, *Errors* and *Gaps* were recorded every 5 min. Normally this test requires the subject to work continuously throughout, but in the present experiment the form was modified to give two versions: in one the subject was allowed a 30 second break or rest pause at the end of each 5 min work. This pause was started by a bell-note and ended by the same sound preceded by the appearance of a warning light. During the break the subject merely sat back in his chair and rested. In the other version the subject worked continuously for the whole 25 min; he heard the bell-note and saw the warning light at the same times as in the former version but his instructions were to ignore them and keep on working. Thus the two versions were kept as similar as possible apart from the presence or absence of breaks. In both the subject worked for 25 min, but the version with breaks was the longer by the addition of the four 30 sec breaks.

In neither version of the test was the subject given any indication of how well he had done either during the test or after.

§ 3. Conditions

Subjects were given each version of the test twice, once with sleep and once with no sleep the previous night. There were thus four possible conditions of testing: *Sleep with Breaks*, *Sleep with Continuous Work*, *No Sleep with Breaks* and *No Sleep with Continuous Work*.

A full discussion of the procedure for withholding sleep is given elsewhere (Wilkinson 1958). Here it will suffice to say that when sleep was withheld subjects assembled in their recreation room where they spent the night awake instead of retiring to bed at 11 p.m. in the normal way. They were under supervision from 11 p.m. until they reported for testing the following morning, but this placed little restriction on them provided they stayed awake.

A subject was always tested at the same time the following morning irrespective of whether or not he had sleep the previous night.

Twelve subjects, all naval ratings between the ages of 18 and 30, were divided into four teams of three and given the four conditions in a Latin Square design shown in Appendix Table 1.

§ 4. Results

Figures 1 and 2 illustrate the trends in *Gaps* and *Corrects* in the four conditions. *Errors* are omitted as they showed no important changes.

Four effects are to be noted in the results:

(*a*) The largest difference occurred between the *No Sleep* and the *Sleep* tests: there were many more *Gaps* and fewer *Corrects* when sleep had been lost. This trend interacted with period of the test, differences being very small at the outset and increasing as the test wore on.

(*b*) In the same way giving breaks resulted in higher levels of performance when compared with the *Continuous* version, but here differences were small and failed to reach significance except for the amount of deterioration during the test in *Corrects*.

(*c*) It is difficult to make comparisons of the effect of breaks on two different indices such as *Gaps* and *Corrects*, but we can say that, compared with the effect of loss of sleep, the effect of breaks was rather greater on *Corrects* than on *Gaps* although the differences did not reach significance for either score.

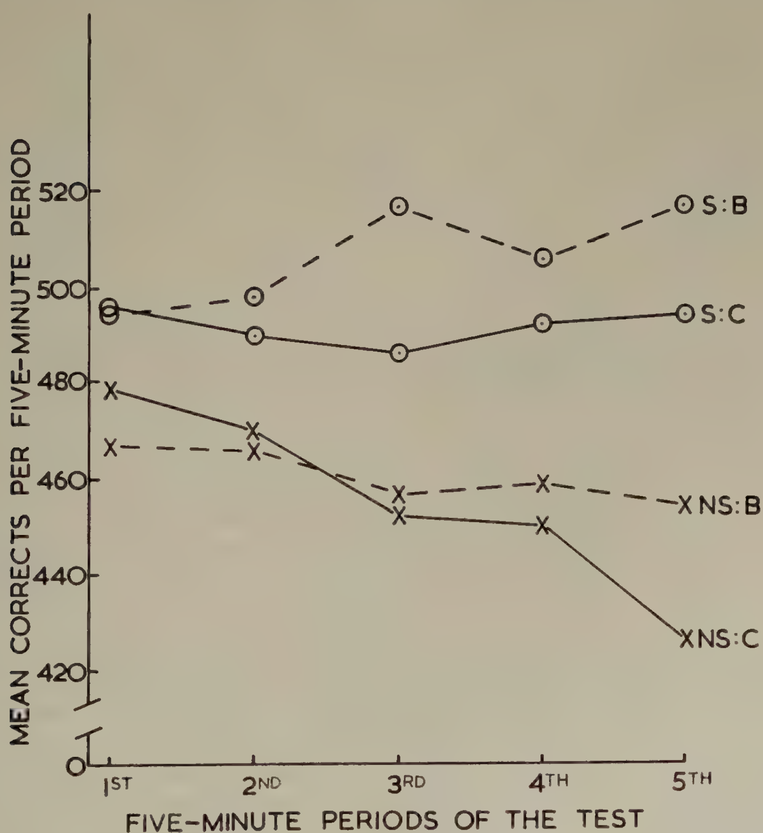


Figure 1. Numbers of *Gaps* in performance occurring under four different conditions in a serial-reaction task. The four conditions are indicated as follows:
S : C = *Sleep with the Continuous Work* version of the task,
S : B = *Sleep* with the *Breaks* version,
NS : C = *No sleep* with *Continuous work*,
NS : B = *No Sleep* with *Breaks*.

(*d*) Finally, and of considerable importance, there was no sign of an interaction between the stress of lack of sleep and that of continuous performance

of the test. The combined effect of the two stresses, as in the *No Sleep with Continuous Work* condition, was no greater than the sum of their two individual effects, as seen in the *No Sleep with Breaks* and the *Sleep with Continuous Work* conditions.

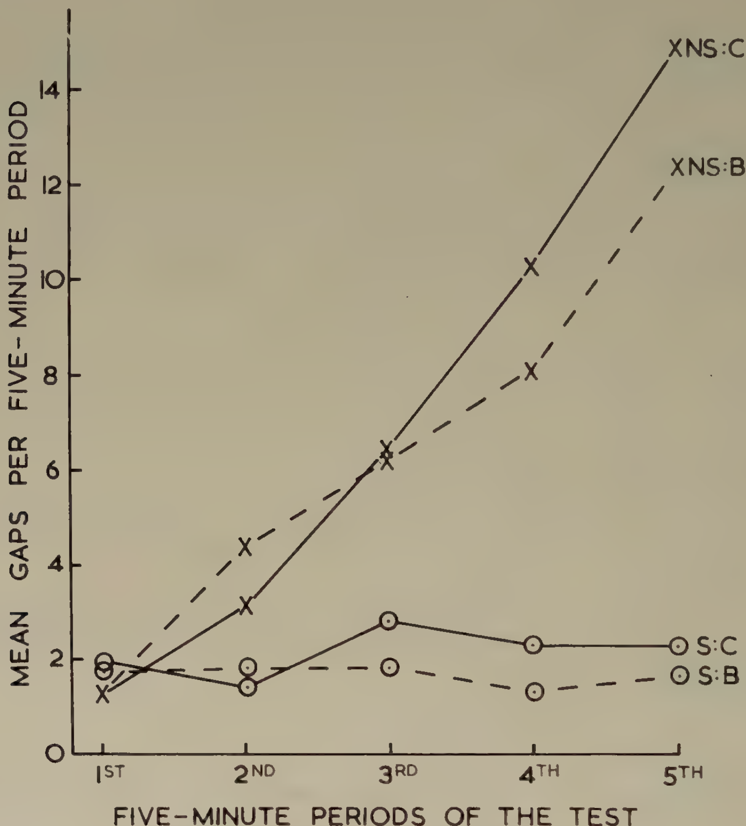


Figure 2. Numbers of Correct Reactions made under four different conditions in a serial-reaction task. The four conditions are indicated as in Fig. 1.

§ 5. Discussion

The results of the present study confirm Pepler's conclusions (1958) that the Five Choice Test of serial reaction is significantly affected after a period as short as 30 hours without sleep. In an area where findings are usually negative and almost always tentative it is comforting to have firm evidence of the influence of so short a term of sleep-deprivation.

The test of serial reaction is affected by stresses other than lack of sleep; it has been shown to give impaired performance as a result of high noise level (Broadbent 1953), excessive warmth (Pepler 1958), anoxia (Bills 1937), and the proprietary drug *Oblivon* (Steinberg 1959). A similar test described by its authors as one of ‘ visual vigilance ’ and known to be affected by lack of sleep (Williams *et al.* 1959) is also an indicator of degrees of unspecified brain damage (Rosvold *et al.* 1956). In the case of all these influences it is the exception rather than the rule for tests to be adversely affected by them and so it is interesting that they should all impair performance of a test of serial reaction.

Although these influences affect performance in different ways, noise, heat and *Oblivon* reducing accuracy while loss of sleep has more effect on level of activity, the implication is that there is a common factor in all these stresses which is effective under the general conditions of this test.

It may be instructive to examine these general conditions and consider in some detail the behavioural changes that occur when the stress of sleeplessness is superimposed. The Five Choice Test presents a relatively changeless situation with, presumably, low levels of sensory input; it allows little variation in response and affords little in the way of immediate and tangible rewards. The test requires constant active response and this may account for there being no occasions when subjects fell asleep as they did over an otherwise rather similar vigilance test (Wilkinson 1958). The Five Choice Test thus has the advantage of showing impairment in a wholly active performance and this makes it perhaps the best choice for further research into the nature of the fatigue which loss of sleep accentuates and the sort of task features which encourage this.

One shortcoming of the test as used in the present experiment is that the apparatus gave no indication of time lapse between each response. It is therefore difficult to tell whether the pattern of fatigue with lack of sleep followed that which Bills (1931) showed to occur in normal subjects: this was an increased incidence of short periods when no response is being made combined with maintenance of normal speed of response during the relatively long intervals between these blocks or gaps. All that can be said at this stage is that towards the end of the tests made under *No Sleep* conditions time lost in scoring *Gaps* did not appear to account for the whole of the decline in speed of responding as indicated by reduced numbers of *Corrects and Errors*. There is, then, a suggestion that the fatigue present with lack of sleep differed in this respect from that observed by Bills; this question needs to be examined more closely using apparatus giving the necessary detailed information.

We must turn now to consider what features of the test and the associated environment contribute most to its sensitivity to loss of sleep. In the present experiment we have examined the continuity of the test in this context and the question is whether the adverse effect of lack of sleep is reduced when short rest pauses are introduced periodically. The answer appears to be 'No'; the difference between *Sleep* and *No Sleep* conditions was almost the same both when continuous work was demanded and when there were breaks, although the confidence limits of the relevant means were rather wide, due, it would seem, to the wide individual differences between subjects in the extent to which they were affected by lack of sleep. It has been suggested (Kleitman 1939) that one of the reasons why some tasks are affected by lack of sleep is that they require *continuous* concentration on the part of the subjects for long periods. The results of this experiment suggest that this should be modified; it may be that, when long periods away from the task are allowed, the fatigue due to lack of sleep may be dissipated, but, apparently, short breaks in the continuity of the work have little effect.

Setting aside questions of lack of sleep for the moment, the short breaks we used had little effect on the fatigue that was present in the task when it was carried out after normal sleep. This contrasts with the work of Mackworth (1950), McCormack (1958) and Colquhoun (1959) who have shown that rest

pauses will reduce fatigue decrements in vigilance tasks carried out by normal subjects. The important difference appears to be the length of the rest pause, never less than five minutes in the above-mentioned work, 30 sec in the present study. The comparison suggests a lower limit somewhere between 30 sec and 5 min below which rest pauses will have little effect in the type of task we have been discussing.

These, then, are the immediate conclusions arising from the present study, but the experiment may serve also as a model for further research on stress in its various forms. It has been noted earlier that the test of serial reaction is affected by many of the more familiar stresses. Using the Five Choice Test it should now become possible to carry out a series of experiments duplicating the present design in which selected stresses are combined and the resultant effect on performance compared with that of each stress acting singly. Here this has been done with the stresses of lack of sleep and continuity of the task; other experiments have combined absence of feedback of knowledge of results with lack of sleep (Wilkinson 1958) and with *Oblivon* (Steinberg 1959), and lack of sleep with heat (Pepler 1958). There are many other possible permutations of stress, and information from a planned programme of this sort on the degree to which the effects of two given stresses are additive or cumulative when combined could give us valuable insight into the extent to which they act in similar ways and through common paths in the central nervous system. At a first approximation the more multiplicative their combined effect the more their modes of action would be deemed to have in common.

This research was done in 1956 for inclusion as part of a doctoral thesis at Cambridge University. It owes much to advice from Professor O. L. Zangwill and Mr. D. E. Broadbent, who directed these studies, and from Dr. N. H. Mackworth, then Director of the Medical Research Council's Applied Psychology Unit where the work was done. I am grateful also to the Medical Research Council for financial support and to the Navy for providing subjects and administrative help. Statistical advice was given by Dr. M. Stone.

Cette étude confirme le fait qu'une privation de sommeil de 30 heures détériore sérieusement la performance vers la fin d'une tâche répétitive de choix multiple effectuée pendant 25 min. En particulier, on constate que la fréquence des blocages, ou temps de réaction anormalement longs, est notablement accrue. C'est ce qui se produit lorsque l'épreuve est effectuée de manière continue; quand on accorde de courtes pauses de 30 sec toutes les 5 min, l'effet de la privation de sommeil reste le même, bien qu'une amélioration de la performance minime et non significative se manifeste de manière égale que le sujet ait été ou non privé de sommeil.

Es wurde bestätigt, dass ein 30 stündiger Schlafverlust die Leistung gegen Ende einer 25 Minuten-Folge von Test-Reaktionen deutlich mindert. Besonders wird das Auftreten von Ausfällen oder ungewöhnlich langen Verzögerungen der Antwort sehr viel häufiger. Das gilt für eine ununterbrochene Testzeit. Werden alle 5 min 30-sec-Ruhepausen eingelegt, so bleibt die Wirkung der Schlaflosigkeit die gleiche. Die Testleistung bei Einlagen von 30-sec-Pausen war unter normalen und schlafberaubenden Bedingungen in gleicher Weise unbedeutend verbessert.

Appendix

Table 1 sets out the Latin Square design used in the experiment.

Table 2 quantifies and gives confidence limits to the results shown in Figs. 1 and 2. The broad assessment of the degree to which performance was impaired as a result of lack of sleep is obtained by taking the sum of the scores in

the two NS conditions (NS : B and NS : C) and subtracting the summed scores in the two S Conditions (S : B and S : C). In the same way the effect of giving breaks is given independently of the sleep variable by (NS : B + S : B)–(NS : C + S : C). The all-important interaction term is obtained by subtracting the NS decrement in the B tests (S : B–NS : B) from the NS decrement in the C tests (S : C–NS : C).

Table 1. The Latin Square administration of the four conditions

	Day 1	Day 2	Day 3	Day 4
Group A (3 subjects)	S : C	NS : C	NS : B	S : B
Group B (3 subjects)	S : B	NS : B	NS : C	S : C
Group C (3 subjects)	NS : C	S : C	S : B	NS : B
Group D (3 subjects)	NS : B	S : B	S : C	NS : C

Table 2. The effect of No Sleep, Continuity of the Test, and the Interaction between the two on performance in terms of Corrects and Gaps

Comparison	Overall score			Within-test deterioration (Q) score		
	5 per cent Conf. limit upper	Mean	5 per cent Conf. limit lower	5 per cent Conf. limit upper	Mean	5 per cent Conf. limit lower
Reduction in numbers of CORRECTS scored when:						
NS is given instead of S, (S – NS)	*+624*	+414	*+204*	*+312*	+211	*+109*
The Continuous version of the test is given instead of the Breaks (B – C)	*+321*	+95	*–131*	*+282*	+148	*+14*
NS is compared with S in the C version instead of the B (Interaction term). (S : C – NS : C) –(S : B – NS : B)	*+137*	–52	*–241*	*+145*	+36	*–73*
Increase in the numbers of GAPS scored when:						
NS is given instead of S, (NS – S)	*+92·9*	48·5	*+4.0*	*+98.5*	+58·8	*+19·1*
The Continuous version of the test is given instead of the Breaks, (C – B)	*+24·2*	+6·0	*–12·2*	*+34·6*	+8·0	*–18.6*
NS is compared with S in the C version instead of the B (Interaction term). (NS : C – S : C) – (NS : B – S : B)	*+17·8*	+1·2	*–15·4*	*+20·0*	+5·7	*–8·6*

Two scores are taken: the Overall Score is the total of *Corrects* or *Gaps* over the whole test; the Q Score, an index of deterioration in performance during the course of the test, is given by the expression $Q = 2(P_5 - P_1) + (P_4 - P_2)$ where P_1, P_2, P_4 and P_5 are the scores in the first, second, fourth and fifth 5-min periods. The confidence limits are shown for a 5 per cent probability level and are derived from a t-test based not on 11 degrees of freedom as would be the

case if all 12 subjects had been treated the same, but on 8 degrees of freedom, i.e. 2 for each team of 3.

References

Bills, A. G., 1931, Blocking: a new principle of mental fatigue. *Amer. J. Psychol.*, **43**, 230–243; 1937, Blocking in metal fatigue and anoxemia compared. *Ibid.*, **20**, 437–452.

Bjerner, B., 1949, Alpha depression and lowered pulse rate during delayed actions in a serial reaction test. *Acta. physiol. Scand.*, **19**, Supp. 65.

Broadbent, D. E., 1953, Noise, paced performance and vigilance tasks. *Brit. J. Psychol.*, **44**, 295–303.

Colquhoun, W. P., 1959, Effect of a short rest pause on inspection efficiency. *Ergonomics*, **2**, 367–372.

Kleitman, N., 1923, S dies in the physiology of sleep. IV. Further observations on the effects of prolonged sleeplessness. *Amer. J. Physiol.*, **109**, 589–593; 1939, *Sleep and Wakefulness* (University of Chicago Press).

Leonard, J. A., 1959, Five choice serial reaction apparatus. *Med. Res. Council App. Psychol. Res. Unit Rep.* No. 326/59.

Mackworth, N. H., 1950, Researches on the measurement of human performance. *Med. Res. Council Special Rep.* Series No. 268.

McCormack, P. D., 1958, Performance in a vigilance task as a function of inter-stimulus interval and interpolated rest. *Canad. J. Psychol.*, **12**, 242–246.

Patrick, G. T. W., and Gilbert, J. A., 1896, On the effects of loss of sleep. *Psychol. Rev.*, **3**, 469–483.

Pepler, R. D., 1958, Warmth and lack of sleep: accuracy or activity reduced. *Med. Res. Council App. Psychol. Unit Rep.* No. 286/58.

Rosvold, H. E., Mirsky, A. F., Sarason, I., Bransome, E. D. Jr., and Beck, L. H., 1956, A continuous performance test of brain damage. *J. Consult. Psychol.*, **20**, 343–350.

Steinberg, H., 1959, Effects of drugs on performance and incentives. Chapter in *Quantitative Methods in Human Pharmacology and Therapeutics* (Pergamon Press).

Warren, N., and Clarke, B., 1937, Blocking in mental and motor tasks during a 65-hour vigil. *J. Exp. Psychol.*, **21**, 97–105.

Wilkinson, R. T., 1957, The effects of lack of sleep on perception and skill. Unpublished Ph.D. Thesis, Cambridge University; 1958, The effects of sleep loss on performance. *Med. Res. Council App. Psychol. Res. Unit Rep.* No. 323/58.

Williams, H., Lubin, A., and Goodnov, J. J., 1959. Impaired performance with acute sleep loss. *Psychol. Monogr.* (in the press).

THE EFFECT OF THE RELATIVE POSITION OF CONTROL AND DISPLAY UPON THEIR DIRECTION-OF-MOTION RELATIONSHIP

By N. E. Loveless

Nuffield Department of Industrial Health, University of Durham,
King's College, Newcastle upon Tyne

The effect upon performance of the direction-of-motion relationship between a control and a display is shown to depend upon certain other features of the layout. When a rotary control knob is used in conjunction with a linear indicator, a clockwise movement of the control is expected to move the pointer upwards or to the right. This expectation is, however, weaker when the centre of rotation of the control is situated on the line of movement of the display than when the control is situated to the side of the line, so that the pointer moves in the same direction as the nearest part of the knob. The orientation of the display and the position of the control have no effect apart from this relationship between them.

§ 1. Introduction

It is a well-established principle of ergonomics that the direction of movement of a control should be 'compatible' with the resulting movement of a display. Certain direction-of-motion relationships between controls and displays are expected by the operator, and performance may be poorer on arrangements which do not conform to these expectations. Thus, the present author has shown (Loveless 1956) that compensatory tracking performance is better when clockwise rotation of a control knob drives a pointer to the right, rather than to the left, on a horizontal linear scale. Similarly, clockwise rotation of the knob was shown to be associated with an upward, rather than a downward, movement of the pointer on a vertical linear scale.

The extent to which performance is affected by these associations may depend, however, on other features of the situation. A comparison of the results obtained with the horizontal and vertical scales, using the layout shown in Fig. 1, is reproduced here as Table 1. An analysis of variance showed that there was no significant difference between the mean scores obtained on the two scales, when differences in the linkage between display and control were disregarded; but the difference between the preferred and non-preferred arrangements was significantly greater for the horizontal scale than for the vertical. This conclusion is confirmed by a re-analysis of the results obtained by Ross *et al.* (1955), who used a paper-and-pencil test, and suggests that the association between control and display is more firmly established in the case of the horizontal scale.

Table 1. Tracking error, control knob below display

Clockwise control movement moves pointer	Mean score	Differences		
		Down	Left	Right
Up	163·0	11·1*	15·3*	9·0*
Down	174·1	—	4·2	20·1*
Left	178·3	—	—	24·3*
Right	154·0	—	—	—

* Significant at 5 per cent level of confidence.

It remains unclear whether this stronger association depends simply upon the orientation of the display, or whether it is a consequence of the relative positions of display and control. In the experiment described above, the control knob was in both cases vertically below the display. The line of movement of the vertical scale therefore passed through the centre of rotation of the knob, but the line of movement of the horizontal scale passed to the side of the knob. It seemed possible that if this relationship were reversed, by placing the knob at the side of the display rather than beneath it, the association between rotation of the knob and vertical indicator movement would now prove the stronger.

It was therefore decided to repeat the experiments with the knob on the right-hand side of the display.

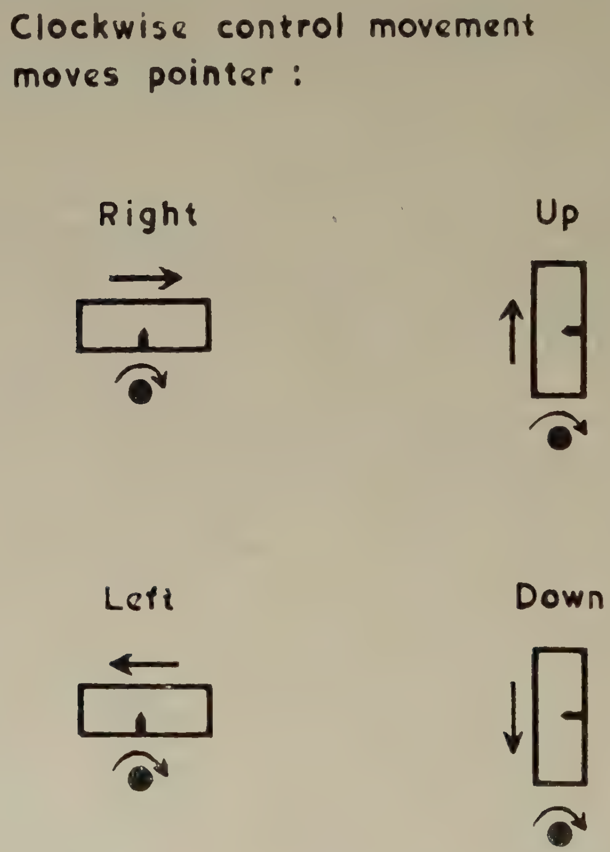


Figure 1. Display-control arrangements used in previous experiment.

§ 2. Method and Results

The compensatory tracking task was identical with that used in the previous experiment, save that the control knob was now situated as far to the right of the display as it had formerly been below it. An electronic integrator provided a measure of tracking error (the scores so obtained being normalized by a logarithmic transformation). The subjects were tested individually. Before the test, the subject was allowed to handle the control knob for 15 sec

to discover the display-control relationship. The test run lasted for 90 sec, but the first and last 15 sec were not scored.

The subjects were seventy-two aircraftmen of the Royal Air Force, all having visual acuity of 20/20 or better as tested by the Snellen chart. Two subjects regarded themselves as left-handed, but habitually used their right hands for some functions, and did not consider themselves handicapped by being required to do so in the present situation. The subjects were randomly divided into groups of eighteen, each group being assigned to one experimental arrangement, according as a clockwise control movement displaced the pointer upward, downward, to right or to left (Fig. 2).

The results are shown in Table 2. They show that the associations between control and display found in the previous experiment were not qualitatively

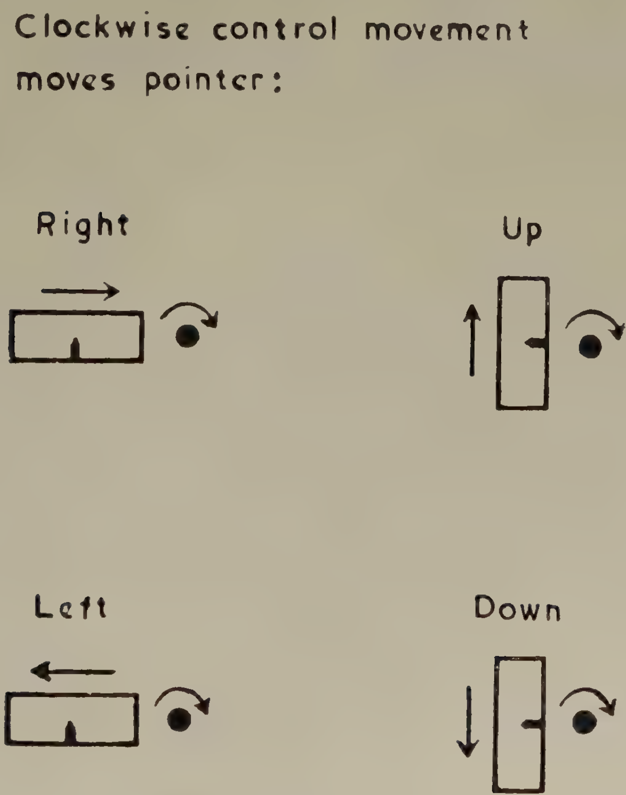


Figure 2. Display-control arrangements used in present experiment.

Table 2. Tracking error, control knob to right of display.

Clockwise control movement moves pointer	Mean score	Differences		
		Down	Left	Right
Up	155·6	25·3*	16·4*	1·7
Down	180·9	—	8·9	27·0*
Left	172·0	—	—	18·1*
Right	153·9	—	—	—

* Significant at 5 per cent level of confidence.

altered when the control knob was shifted to the right of the display. The mean score obtained when a clockwise control movement displaced the pointer upward was significantly better than when it displaced the pointer downward; and the mean score when it displaced the pointer to the right was significantly better than when it displaced the pointer to the left. The result for the vertical scale is in agreement with the findings of Warrick (1947).

As in the previous experiment, an analysis of variance showed that there was no significant difference between the horizontal and vertical scales in overall mean score, when differences in drive are disregarded. In contrast to the previous experiment, however, the two scales show no significant difference in the strength of the association between control and display.

Table 3. Tracking error, combined experiments. Analysis of variance

	Source of variation	Degrees of freedom	Mean squares	F
1.	Scale orientation	1	532	2·81
2.	Drive	1	13983	73·88*
3.	Control position	1	77	0·41
4.	1×2	1	83	0·44
5.	1×3	1	105	0·56
6.	2×3	1	955	5·05*
7.	$1\times 2\times 3$	1	143	0·76
8.	Subjects treated alike	136	189	—

* Significant at 5 per cent level of confidence.

The meaning of this result is best brought out by combining the results from the two experiments, as shown in Table 3. In this analysis of variance, the main effect ' Drives ' contrasts the preferred and non-preferred arrangements (i.e. ' Up ' and ' Right ' *versus* ' Down ' and ' Left ') on both displays; the main effect ' Control positions ' contrasts those arrangements in which the centre of the control is situated on the line of movement of the display (i.e. ' Up ' and ' Down ' in the former experiment and ' Right ' and ' Left ' in the present one) with those in which it is situated to the side of the display (i.e. ' Right ' and ' Left ' in the former experiment and ' Up ' and ' Down ' in the present one). It will be seen that there was a significant interaction between these effects, indicating a weaker association between control and display when these are in line with each other. The difference in orientation of the two displays (horizontal or vertical) has no significance as a main effect or in interaction with either of the other variables.

§ 3. Discussion

The results of the two experiments show that when a rotary control knob is used in conjunction with a linear indicator, a clockwise movement of the control is expected to drive the pointer upwards or to the right; and that this expectation is weaker when the line of movement of the display passes through the centre of rotation of the knob than when the knob is situated to the side of the display. Within the limits of the arrangements tested, the orientation of the display and the position of the knob have no effect apart from this relationship between them. A possible explanation for the influence of this factor of relative position may be found in the suggestion by Warwick (1947) that an indicator is expected to move in the same direction as the nearest

point of the control, to the extent that better performance was obtained from arrangements to which this principle could be applied. Results from experiments on circular scales (Loveless 1956) show that the principle is not of general application, but it may nevertheless embody an element of truth. The question might be settled by experiments in which the control was above or to the left of the display.

Even if the principle were established, arrangements in which the line of display movement passes through the centre of rotation of the control would seem to occupy a neutral position with respect to it. They are arrangements in which the operator's expectations are less prominent, but they do not require any established habits to be reversed. There is therefore no reason to fear that the operator will revert to an earlier habit under emergency conditions, as is the case with arrangements which contravene his expectations (Simon 1954). This point is of some practical consequence, since arrangements of this kind have their advantages, especially where a number of indicators and their associated controls are to be mounted on the same panel. In this situation, such an arrangement readily allows the scales to be aligned for check-reading (Murrell *et al.* 1952), is economical of space, and indicates clearly which control is associated with each display.

The work reported here was carried out for the Flying Personnel Research Committee, under the direction of Professor R. C. Browne. The author is grateful to the Officer Commanding the Royal Air Force Station, Middleton St. George, for his courtesy in making subjects available.

L'effet sur la performance de la relation entre la direction de déplacement d'une commande de contrôle et celle du signal indicateur associé dépend de certaines autres caractéristiques de l'arrangement. Lorsqu'on se sert d'un bouton rotatif pour contrôler un indicateur à déplacement linéaire, on s'attend à ce qu'un mouvement du bouton dans le sens des aiguilles d'une montre déplace l'indicateur soit vers le haut, soit vers la droite. Cependant, on s'y attend moins quand le centre de rotation de la commande de contrôle est situé sur la ligne de déplacement du signal indicateur que dans le cas où ce centre est placé à côté de la ligne, de telle sorte que le repère se déplace dans la même direction que la partie la plus proche du bouton. L'orientation du dispositif indicateur et la position de la commande de contrôle n'ont pas d'autre effet, mis à part cette relation.

Die abhängigkeit der Leistung von dem Verhältnis der Bewegungsrichtungen einer Steuer- und Folge-Bewegung wird in folgender Weise von der Anordnung beeinflusst : Wird ein Steuer-Drehknopf in Verbindung mit einem linearen Zeiger benutzt, so erwartet man bei einer Drehung im Uhrzeigersinn eine Rechts- oder Aufwärts-Bewegung des Zeigers. Diese Erwartung ist aber schwächer, wenn der Mittelpunkt des Drehknopfes in der Bewegungslinie des Zeigers liegt, stärker dagegen, wenn der Drehknopf seitlich von der Bewegungslinie des Zeigers sich befindet, dh. sich in der gleichen Richtung wie der nächste Punkt des Knopfes bewegt. Die horizontale oder vertikale Lage von Knopf und Zeiger beeinflussen ihre gegenseitige Beziehung nicht.

References

Loveless, N. E., 1956, Display-control relationships on circular and linear scales. *Brit. J. Psychol.*, **47**, 271–282.

Murrell, K. F. H., Murch, S. J., Suffield, N. G., and Morley, N. J., 1952, A comparison of three dial shapes for check-reading instrument panels. *Naval Motion Study Unit Report No.* 51.

Ross, S., Shepp, B. E., and Andrews, T. G., 1955, Response preferences in display-control relationships. *J. appl. Psychol.*, **39**, 425–428.

Simon, C. W., 1954, Effects of stress on performance in a dominant and a non-dominant task. *USAF WADC Technical Report No.* 54–285.

Warrick, M. J., 1947, Direction of movement in the use of control knobs to position visual indicators. In *Psychological Research on Equipment Design* (Edited by P. M. Fitts) (Washington: U.S. Govt. Printing Office), Ch. 9.

SIGHTING WITH AIDED AND UNAIDED VISION

By H. C. W. Stockbridge and J. B. Chambers

Clothing and Stores Experimental Establishment, Ministry of Supply, U.K.

Six subjects carried out three experiments using open vision and vision assisted by a monocular or by binoculars. A shorter response time was found when subjects switched attention from open to monocular assisted vision than when a head movement from open vision to binocular assisted vision was required.

A sight was required for an anti-tank guided missile. The operator of this missile has first to acquire a target (i.e. a tank), possibly using a telescope having a limited field of view. He must then gain control of his missile as quickly as possible, and since the missile has a wide dispersion, he uses the naked eye. As soon as he has guided his missile into the field of view of his telescope, he uses the telescope to direct the missile on to the target.

Two methods of sighting were considered. In the first the subject used both eyes and either looked over or through a pair of binoculars. In the second method the subject either looked through a monocular with one eye or used the other in unaided vision. A comparative estimate of the time taken by each method was required.

The objects of the experiments were therefore:

(*a*) To estimate the time required to change from open to aided vision and vice versa.

(*b*) To compare the time required to use a binocular and a monocular sight, using a laboratory simulator.

§ 1. Apparatus and Method

1.1. *Switching Viewing from Open to Binocular Sights* (*Experiment* 1)

The subject in this experiment gazed over a pair of binoculars. As soon as a light bulb was switched on by the experimenter he dropped his head and looked through the binoculars ($\times 6$) at a Landolt ring 8 yds away. This Landolt ring was 7/32 in. in diameter (subtending 2 min 40 sec of arc at the eye) and had a break of 3/64 in. in it which could be seen through the binoculars but not with the naked eye. This break subtended 35 sec of arc at the eye, or 3 min 30 sec of arc allowing for the magnification of the binoculars; thus the break when magnified was easily visible. A brow switch was mounted above the binoculars and the subject by pressing this switch, stopped an electric timer which the experimenter had started by switching on the light bulb. The brow switch also started another clock. If the gap in the Landolt ring was uppermost the subject did not react but if the break was at the bottom of the ring he broke a circuit which stopped the second clock.

Thus two times were obtained. The first clock gave a simple reaction time to a light intended to represent the missile. The second clock gave the time taken for the subject to decide whether or not his sight was still pointing at the target.

It had been found from a pilot trial that subjects improved negligibly after 20 trials. For the experiment 20 learning trials were given and the last 10 of these trials had to be correct. If a false response to the Landolt ring was made, a further 10 correct trials were required.

For the experiment proper, random presentations of the ring in the up and down position were made until 16 correct responses had been given. If an error was made in a set of 10 presentations, these results were cancelled and another 10 were given. (Five of the subjects used were laboratory workers in their twenties or thirties while the sixth was a mechanic in his fifties.)

1.2. *Binocular to Open Sights* (*Experiment* 2)

The second experiment employed the same apparatus. The subject removed his eyes from the binoculars as soon as he saw the light. He then looked at a Landolt ring of $1\frac{3}{8}$ in. diameter with a $\frac{1}{4}$ in. break, 8 yds away as before. Thus the Landolt ring subtended an angle of 16 min 25 sec of arc while the break subtended an angle of 2 min 55 sec and was thus easily visible without magnification. The timing arrangements were similar to those used in the first experiment, two times being obtained. The same six subjects were used and the same training procedure employed as in Experiment 1.

The same procedure was used as in the first experiment.

1.3. *Open to Monocular Sight* (*Experiment* 3)

As in the previous experiments the subject saw first a light and then a Landolt ring. As soon as he saw the light, the subject pressed a key which stopped the first clock, started the second and opened a shutter revealing the Landolt ring. As before if, and only if, the ring was turned so that the gap was below the centre, the subject pressed a second key, stopping the second clock and giving the second time noted.

Two collimating lenses, by making the display appear at an infinite distance away, rendered accommodation unnecessary.

Three of the six subjects used in the previous experiments saw the light with their left eyes first before looking at the Landolt ring with their right eyes, while the remaining three subjects first saw the light with their right eyes and then saw the ring with their left eyes. The two groups of subjects then carried out the experiment in the reverse order.

The Landolt ring used was of the same dimensions as that described in the first experiment.

The same training procedure and lighting conditions were used as in the previous experiments.

Mean total times in seconds for 16 trials

Experiment	Condition	Subject 1	2	3	4	5	6	Mean
1	Open-Binocular	1·56	1·74	1·89	1·46	1·57	1·62	1·64
2	Binocular-Open	1·21	1·11	1·50	1·26	1·16	1·10	1·22
3	Open-Monocular L-R	1·06	0·91	1·12	1·09	0·96	0·87	1·00

§ 2. Results

The table shows the Binocular-Open condition as having been quicker than the Open-Binocular condition by, on average, 0·42 sec. The simplest and most probable explanation of this is that in the Binocular-Open condition it was not necessary to centre the eyes on the binoculars. The Open-Monocular condition was quicker than the Binocular-Open condition by an average of 0·22 sec, presumably because no head movement was required.

The comparison of principal interest, however, is between the first and third experiments, where it is seen the Open-Monocular condition was quicker than Open-Binocular by $0{\cdot}64 \pm 0{\cdot}07$ seconds ($t = 8{\cdot}8$ with 5 d.f. $P < 0{\cdot}001$). In other words, on the basis of the subject means, if instead of the Open-Binocular condition the Open-Monocular condition is used, there is a mean saving in time of the order of 40 per cent.

The accuracy of this figure is qualified by the time variation; the experiments not having taken place at the same time. The second experiment was in fact suggested by the first. In this interval the subjects or their environments might have changed. However, had the experiments taken place at the same time, difficulties with transfer of training might have been experienced unless large matched or random groups had been used.

The authors wish to thank Mr. C. B. Gibbs for his advice. This paper is published with the permission of the Controller H.M.S.O.

Six sujets ont participé à trois expériences d'inspection en vision simple et en vision facilitée par des lunettes monoculaire ou binoculaire (vision armée).

En passant de la vision simple à la vision par lunette monoculaire, les sujets se sont adaptés plus vite qu'on passant de la vision simple à la vision par lunette binoculaire, où un déplacement de la tête était nécessaire.

6 Versuchspersonen führten 3 Experimente durch, bei denen sie freies Sehen und Sehen durch ein monoculares bzw. binoculares Fernglas verwendeten. Eine kürzere Reaktionszeit wurde gefunden, wenn die Versuchspersonen vom freien Sehen mit einem Auge zum monocularen Sehen mit dem anderen Auge ohne Kopfbewegung übergingen, als wenn sie vom freien Sehen mit beiden Augen durch eine Kopfbewegung zum binocularen Sehen durch ein Fernglas überwechselten.

THE ENERGY EXPENDITURE OF WALKING ON SNOW AT VARIOUS DEPTHS

By A. O. Heinonen, M. J. Karvonen and R. Ruosteenoja
Institute of Occupational Health, Helsinki

The energy expenditure of walking at natural pace on snow was determined. The results are expressed as a function of the depth of the depression of the feet into the snow. Depressions of 0, 10, 20, 30 and 40 cm gave an energy expenditure of 0·63, 1·42, 2·65, 5·72 and 8·30 cal/kg body weight per horizontal metre, respectively. The energy expenditure could be expressed as a linear function of the depression, using two equations, one for depressions less than and the other for those greater than 15 cm. The results are discussed.

A study on the energy expenditure of walking on several types of surface has been published (Glasow and Müller 1951). For walking on soft snow at the speed of 60–66 m per min with an extra load of 20 kg, Christensen and Högberg (1950) give energy expenditure values of 15·2–20·2 kcal per min. On hard snow at the speeds of 100–152 m per min, the cost varied from 8·4 to 16·2 kcal per min.

Lundgren *et al.* (1955) published several observations on the energy expenditure of walking on snow. The depth of snow varied from 5 to 42 cm. However, no systematic study of the influence of the depth of snow upon energy expenditure was made. In the present paper the results will be described of the energy expenditure of walking on snow of various depths, the depth of the snow being measured as the distance the feet sink into the snow. The writers are not aware of any other investigations on this subject.

§ 1. Methods

The experiments were made on snow on level fields. The subjects walked at their natural walking pace. The distance walked in each measurement varied from 45 to 180 m. The consistency of the snow was not homogeneous throughout. There was a surface layer of 2–3 cm of soft snow, next a harder layer of 2–4 cm depth, again a few centimetres of soft snow and a thin hard layer. Under this, the snow was homogeneous, with varying granular size. The depression made in the snow by the feet was measured from the surface to the point corresponding to the ball of the foot. The mean depression was calculated from 30–50 measurements in each test. Seven males served as subjects. The age range was from 16 to 27 years, stature from 165 to 180 cm, and weight with clothing from 65 to 80 kg.

The energy expenditure was determined with the aid of the Max Planck respirometer (Müller and Franz 1952). Oxygen in the samples of expired air was determined with the aid of a Pauling–Beckman magnetometric oxygen analyser, which was calibrated by the use of the Scholander micro-gas analysis apparatus (Scholander 1947). The energy expenditure was calculated directly

from the oxygen content of the expired air, a method which is insensitive to variations in the RQ (Weir 1949).

The resting (sitting) energy expenditure was determined during 5 min immediately before each series of tests. In addition to the actual time of walking, the oxygen uptake was determined during 4–8 min after each test, in order to include an eventual oxygen debt. The energy expenditure is expressed as cal/kg body weight per horizontal metre walked (cal/kg/hor. m) which figure denotes the caloric cost of locomotion per unit of mass moved.

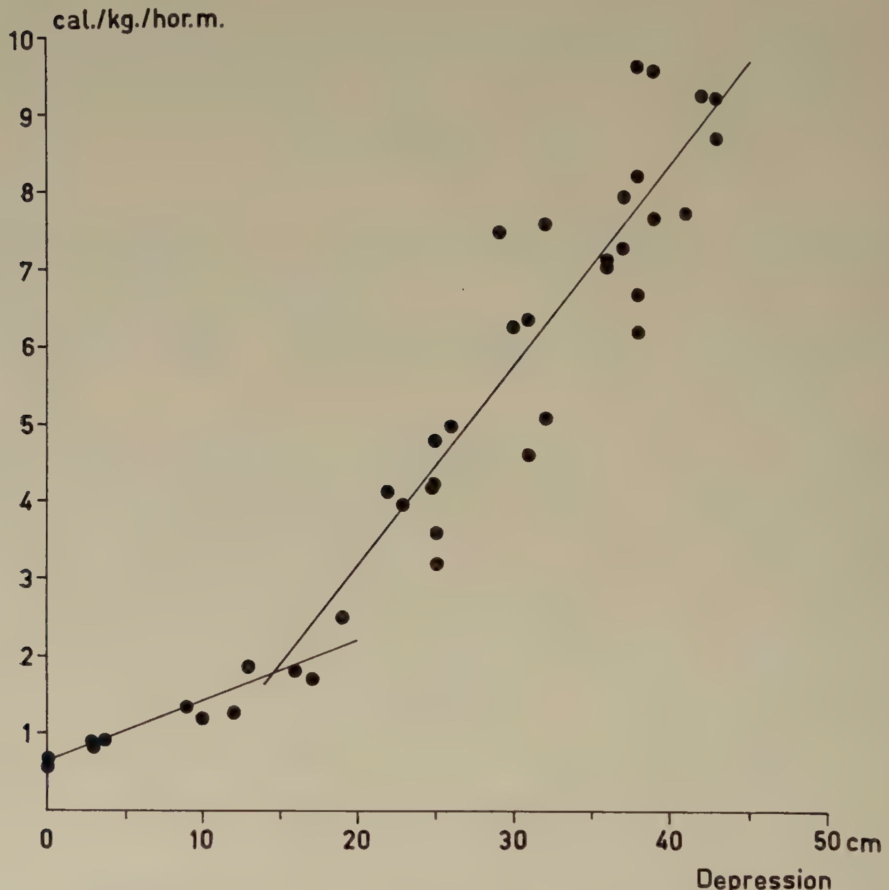


Figure 1. The energy expenditure of walking on snow, expressed as cal/kg body weight per horizontal metre, plotted against the depth depression in the snow. Each point denotes an individual experiment. The straight lines correspond to the regression equations presented in the text.

§ 2. Results

Energy expenditure plotted against the depression in the snow is shown in Fig. 1. The distribution of the values suggests two linear relationships with an intersection at approximately 20 cm depression. On this assumption,

linear regression equations were calculated for the data below 20 cm depression and for those above it. The equations are :

$$x_1 < 20, \qquad x_0 = 0{\cdot}634 + 0{\cdot}0786x_1, \qquad P = 0{\cdot}001; \quad . \quad . \quad . \quad (1\,a)$$

$$x_1 > 20, \qquad x_0 = -1{\cdot}986 + 0{\cdot}2570x_1, \qquad P = 0{\cdot}001; \quad . \quad . \quad (1\,b)$$

where x_0 = work (cal/kg/hor. m), and x_1 = depression (cm). The two lines actually intersect at 15 cm.

The results were also plotted on a semi-logarithmic chart (Fig. 2). They are seen to be linearly distributed, and the regression equation becomes :

$$\log x_0 = -0{\cdot}1149 + 0{\cdot}0270x_1. \quad . \quad . \quad . \quad . \quad . \quad (2)$$

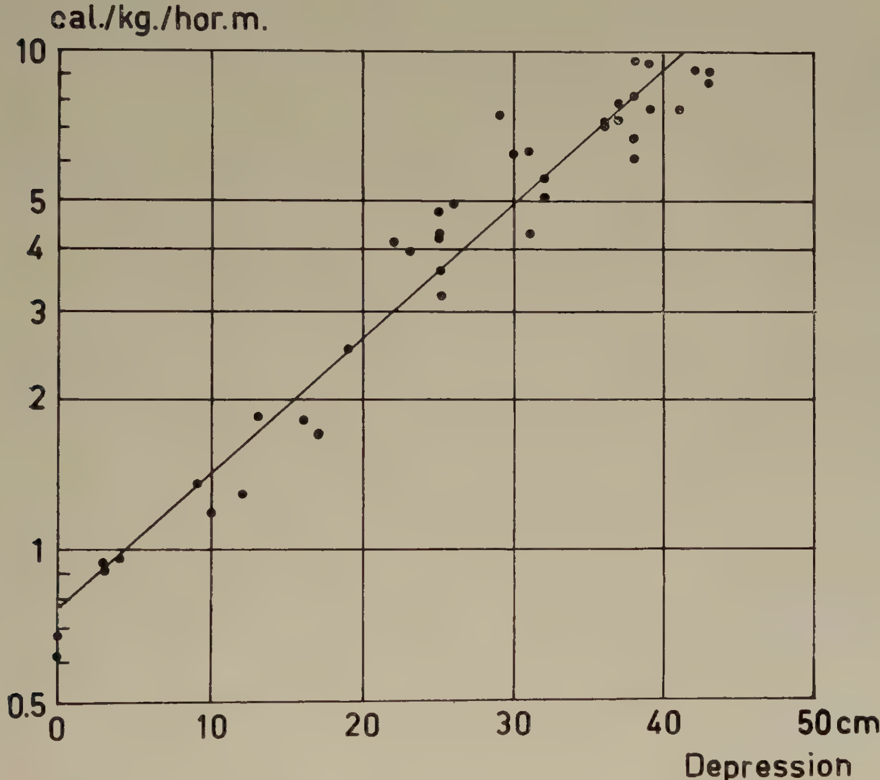


Figure 2. The energy expenditure of walking on snow, on a logarithmic scale, as plotted against the depression in the snow, on an arithmetic scale. The straight line corresponds to the regression equation presented in the text.

Speed and the length of stride in walking on snow of varying depth

Depression (cm)	Mean speed (metres/min)	Length of stride (cm)
0	102	71–83
1–10	87	62–71
11–20	61	53–59
21–30	38	48–50
31–43	21	43–48

The speed of walking and the length of stride decreased, as the snow became deeper. The table shows the results obtained. With a deepening of the snow from 0 to 43 cm the speed decreased to one-fifth and the length of the stride was almost halved.

§ 3. Discussion

The results show that walking on snow is a very strenuous form of locomotion. A depression of 10 cm in the snow increases the energy expenditure to 1·4 cal/kg/hor. m, i.e. by a factor of 2·2 from walking on firm ground. With a depression of 20 cm the factor becomes 4·1, at 30 cm 8·8, and at 40 cm the energy expended is 12·8 times that on firm ground.

When the present results are compared with those of other investigators on other kinds of surface than snow, the expenditure while walking on firm ground is found to be slightly higher than the values obtained by most investigators (Glasow and Müller 1951, Henry 1953, Passmore and Durnin 1955), but lower than those of Lundgren *et al.* (1955). The depression of 4 cm in snow corresponds to the expenditure while walking on a superficially ploughed stubble field (depth of ploughing 10–12 cm) and the depression of 9 cm in snow with that on a deeply ploughed and harrowed field (Glasow and Müller 1951).

The data published by Christensen and Högberg (1950) on walking on snow indicate that their lowest figure, 8·4 kcal per min at the speed of 100 m per min, which gives a cost of 1·05 cal/kg/hor. m for a 80 kg man, corresponds to a depression of 6 cm in the present study. Their highest figure, 20·2 kcal per min, for a man with a total weight of 100 kg at the walking speed of 66 m per min, gives a cost of 3·1 cal/kg/hor. m ; this corresponds to a depression of 22 cm.

The figures of Lundgren *et al.* (1955) indicate the depth of the snow layer but not that of the depression. Walking on pasture, 5–10 cm snow, at the speed of 88 m per min, increased the cost to 1·6 times that of walking on road at 100 m per min ; in the present study a corresponding increase is observed, when the depression is 5 cm. On snow of 32–42 cm at a speed of 50 m per min, the expenditure observed by them was 2·45 cal/kg/hor. m, which according to the present data corresponds to a depression of 18 cm. These depressions appear very probable on the layers of snow indicated ; the data of the two studies evidently are in good agreement.

It is interesting to compare the present results with those of Cotes *et al.* (1957, 1958), who expressed the energy expenditure of walking as a linear function of the lift-work. The depression of feet into the snow obviously necessitates some increase of the height of lift. With full equivalence of lift and depression, at 15 cm depression, the lift would be 0·268 m per horizontal metre walked (= depression 15 cm, divided by the length of stride, 56 cm). The difference in energy expenditure between walking on firm ground and 15 cm snow, respectively, is 1·2 cal/kg/hor m, or 0·513 kg m. When 0·513 kg m energy is expended to lift a kilogramme 0·268 m vertically, the mechanical efficiency of work is 52 per cent. A similar calculation for depressions between 15 and 37 cm gives a mechanical efficiency of 23 per cent only. In the work of Cotes *et al.* already cited, the mechanical efficiency of lift work was 30·8 per cent ($E = 3{\cdot}25 W_2 + 2{\cdot}4$, both sides expressed as kcal/min). It may be

concluded that walking on shallow snow does not cause an increase in lift comparable to the depression, whereas on deep snow, the energy expenditure increases more than is ascribable to lift work only.

The breaking of the graphic relation into two straight segments (Fig. 1) suggests that the movements involved change in deeper snow. This is obvious : no ballistic movements of the legs can be used, and the walker assumes a forward stooping posture. The posture by itself increases energy expenditure of walking : a stooping to the height of 80 per cent of stature by 30–50 per cent, to the height of 60 per cent by 350 per cent (Bedford and Warner 1955). The difficulty of balancing in soft snow, and the slipperiness (Hietanen *et al.* 1928), particularly of wet snow, evidently also contribute to the increase in energy expenditure.

Two types of plotting are presented in Figs. 1 and 2. The simplest distribution of the data, a straight line, is obtained on a semi-logarithmic plot. However, the authors are not aware of any description of body mechanics which corresponds to this form of presentation. The linear relation obtained is therefore regarded as a coincidence only. The reason for its presentation is to give an example of a situation in which conclusions based on the simplicity of structure would lead to a result, for which no mechanical model could be perceived. Reasoning based on statistics only is obviously not the best method in such a situation.

La dépense énergétique de la marche dans la neige à allure normale a été mesurée et exprimée comme une fonction de la profondeur de l'enfoncement des pieds dans la neige. Les enfoncements de 0, 10, 20, 30 et 40 cm ont exigé des dépenses énergétiques respectivement de 0·63, 1·42, 2·65, 5·72 et 8·30 calories par kg de poids corporel et par mètre d'avancement horizontal. La dépense énergétique peut s'exprimer comme une fonction linéaire de l'enfoncement, à condition d'utiliser deux équations, l'une pour les enfoncements de moins de 15 cm, l'autre pour les enfoncements de plus de 15 cm.

Der Energieumsatz beim normalen Gehen im Schnee wurde untersucht. Die Resultate wurden als Funktion der Eindruck-Tiefe des Fusses in den Schnee dargestellt. Eindrücke von 0, 10, 20, 30 und 40 cm gaben einen Energieaufwand von 0·63, 1·42, 2·65, 5·72 und 8·30 cal/kg Körpergewicht je Meter Weg. Der Energieumsatz konnte als lineare Funktion der Eindruck-Tiefe dargestellt werden. Er folgte 2 Gleichungen, einer für Eindrücke geringer als 15 cm und der andere für solche die grösser als 15 cm sind. Die Resultate werden diskutiert.

References

Bedford, T., and Warner, C. G., 1955, The energy expended while walking in stooping postures. *Brit. J. industr. Med.*, **12,** 290–295.

Christensen, E. H., and Högberg, P., 1950, Physiology of skiing. *Arbeitsphysiologie*, **14,** 292–303.

Cotes, J. E., Meade, F., and Wise, M. E., 1957, Standardisation of test exercise. *Fed. Proc.*, **16,** 25–26 ; 1958, Variations in the vertical work done against gravity and in the energy expenditure of walking, between men and women and in relation to training. *J. Physiol.*, **141,** 28–29P.

Glasow, W., and Müller, E. A., 1951, Das Gehen auf verschiedenen Böden. *Arbeitsphysiologie*, **14,** 319–321.

Henry, F. M., 1953, The oxygen requirement of walking and running. *Res. Quart. Amer. Ass. Hlth phys. Educ.*, **24,** 169–175.

Hietanen, A., Nikkinen, M., Nyyssölä, H., and Sternberg, G., 1928, Der Stoffwechsel beim Gehen auf glatter Fläche. *Skand. Arch. Physiol.*, **54,** 145–148.

Lundgren, N., Sundberg, U., and Lindholm, A., 1955, A study of the heaviness of work in using power saws in timber cutting (Swedish, with English summary). *Medd. Skogsforskn-Inst. Stockh.*, **45**, No. 10, 1–46.

Müller, E. A., and Franz, H., 1952, Energieverbrauchsmessungen bei beruflicher Arbeit mit einer verbesserten Respirations-Gasuhr. *Arbeitsphysiologie*, **14**, 499–504.

Passmore, R., and Durnin, J. V. G. A., 1955, Human energy expenditure. *Physiol. Rev.*, **35**, 801–840.

Scholander, P. F., 1947, Analyzer for accurate estimation of respiratory gases in one-half cubic centimeter samples. *J. biol. Chem.*, **164**, 235–250.

Weir, J. B. de V., 1949, New methods for calculating metabolic rate with special reference to protein metabolism. *J. Physiol.*, **109**, 1–9.

A NEW APPROACH TO TEACHING INDUSTRIAL MANAGEMENT

By F. J. Willett

Department of Engineering, University of Cambridge

A one-year course in the Principles of Industrial Management has been established in the Department of Engineering of the University of Cambridge. Entry to the course is restricted to students who have qualified for a degree in a scientific subject.

The course is not intended as training in management but as a grounding in the analysis of industrial problems and behaviour. There will be stress on the development of formal analytic models, and in particular, on those based on statistics, but there will be considerable effort to suggest that other problem areas, less easily quantified, may be tractable given effective techniques.

The Department of Engineering in the University of Cambridge has for many years been interested in the teaching of management subjects. In March 1959 it laid before the University outline proposals for its first major offering in this field (*Camb. Univ. Reporter* 1959); a one-year course in the Principles of Industrial Management, designed for men who already have satisfied the University's examination requirements for a degree in Mechanical Sciences, Natural Sciences or Mathematics. These men may not have completed their necessary terms of residence and so the course may be read in either the third or the fourth year. The course is not a true post-graduate one in the sense that it is not intended for men returning from industry with a considerable body of experience.

The University accepted these proposals for an experimental period of five years and teaching will begin in October 1959. The course is radically different from any other long-term management programme in this country in its restriction to scientists and technologists and in its emphasis upon mathematical analysis. In these respects, the design of the course has drawn much from the experience of such American institutions as M.I.T. and the Carnegie Institute of Technology at Pittsburgh.

The primary objective is to give some insight into the various fields of knowledge that underlie managerial behaviour and into the patterns of analysis that are effective in these fields. Much of the emphasis of the course will be to show that large areas of the managerial environment are tractable under analysis, given effective analytical tools. The course is not concerned with training men in the activities necessary for a manager.

Men passing through this course will be assuming significant managerial responsibility during the 1970's at the earliest. From a conservative projection of the rate of change of business activity and organization, it is certain that little of the accepted ' technique ' of management today will be viable by that time and it would appear probable that developments in fields such as high-speed data processing will have altered the whole basis of organization structure. If this is a true prediction then the case is greatly reinforced for disregarding skills and activities and addressing the course to the development of analytical processes of broad generality, and of a general framework in which an individual can develop his own further education.

Management, in the sense that it is a decision-making process, will become more rational and more analytic. This will mean increasing use of elaborate mathematical tools, but, more critically, it will demand an increase in the clarification and quantification of the variables that need to be considered. The many vague and intuitively evaluated variables and the largely implicit logical models used in present-day decisions will need to be made explicit and the logic improved.

A further consequence of industrial change is that the Company and its managers will need a developed sense of its social environment and social responsibilities. Industry will need to participate in a conscious fashion to an increasing extent in the socio-economic process of society, and its relation to society will depend upon this participation rather than on the older criteria of production and price. The role of the manager is thereby complicated and he must be sensitive to general social movements.

The subject matter of the course is organized around five examination papers, which are described in the proposal as :

Paper 1. *Quantitative Analysis and Control*

The paper shall consist mainly of questions on :

The application of scientific method to industrial problems. The design of experiments.

Statistics applied to the analysis and control of technological processes.

Operations analysis, linear programming, queue theory, incremental analysis.

Paper 2. *Human Behaviour in Industry*

The paper shall consist mainly of questions on :

Elements of social structure with particular reference to small groups. Human problems in industry; motivation and morale.

Applied experimental psychology and its relation to the design of equipment, work methods, fatigue and training.

The social problems of technological change.

Paper 3. *Industrial Organization*

The paper shall consist mainly of questions on:

Organization considered as a system for the division of labour, as a system of authority, and as a communication system.

The effect of position in the formal structure upon the attitude and behaviour of individuals.

Comparative studies of existing organizations and systems of control.

Paper 4. *Economics, Finance and Accounting*

The paper shall consist mainly of questions on :

(*a*) *Economics*

The influence of fiscal and monetary policy upon the level of industrial activity. Problems of inflation, balance of payments, etc.

Economics of the firm; cost concepts, supply and demand. Factors affecting wages, profits and prices.

State control of monopoly and restrictive practices.

(*b*) *Finance and Accounting*

Financing of industrial concerns.

Accounting and the control of internal finance.

Cost Accounting, considered chiefly as an aid to Management Control.

Paper 5. *The Social Environment of Industry*

The paper shall consist mainly of questions on :

(*a*) *Economics and Social History*

The development of an industrial economy and the consequent social values.

(*b*) *Law*

The development of the formal regulation of industry within the English legal system.

When considered in terms of separate papers, the subjects may appear to be a series of discrete topics; they will not be so treated in the actual teaching. It may be of interest to look in greater detail at the content of two of these papers.

The teaching for the first paper covers the ground that is the special emphasis of the course and additionally provides the necessary tools for analytic work in

other areas. The main concern is with the development of statistical and mathematical models for the analysis of industrial activities. The aim is for a considerable degree of mathematical sophistication rather than experience with applications; a debatable premise for the mathematics have already gone some way in advance of application, but useful application is more likely to develop from understanding of the fundamental tools than the reverse. It is however true that a major problem will be to ensure that the tools are regarded as sources of information for the decision process rather than subjects in their own right. There must be some learning of technique as such but this must be disciplined into an approach that stresses the relevance of the quantitative, model-making attitude to the real world.

This is a valuable emphasis for the student body for whom the course was designed, for, firstly, it constructs a bridge between their previous education in the analysis of physical phenomena, and secondly, if paradoxically, it is difficult to go far with explicit quantitative model-making in the industrial sphere without being faced with variables that are qualitative but which must be evaluated.

While most of the application presented will be associated with problems of finding normative solutions to questions arising from the search for industrial efficiency, there should be opportunity to look at some of the descriptive models that have been developed in the social sciences and general system analysis including, for example, game theory, the work of Phillips, Forrester and Tustin (see e.g. Forrester 1958, Tustin 1953) on servo-mechanistic analogies of the economy, and the ideas formalized by Simon (1957).

The second paper has four major aspects. First to develop a set of ideas for describing the relation of an individual with his environment, drawing upon an admittedly sociologically biased personality psychology. The content of this phase is best illustrated by the selection of Newcomb's *Social Psychology* (1955) as required reading. In the second stage the focus will be upon the individual and the small group; developing the material of Newcomb's last chapters on role and status with ideas on group structure and function that stem mainly from the work of Homans (1951) and Festinger (1950). Here too there would be some consideration of the experimental studies in communication efficiency and group satisfaction, in leadership roles, and an introduction to ideas in sociometry.

This work must then be put into an industrial setting and attention given to the range of industrial studies that began with Hawthorne, looking at these both for content and for methodology. It seems probable that the new Harvard book " The motivation, productivity and satisfaction of workers " by Zaleznik, Christensen and Rothlisberger (Zaleznik 1958) will prove invaluable in this context.

Finally in the syllabus for this paper, there will be a fairly brief survey of the approach and attitude of the experimental psychologist to the problems of the relation of man, machine and work environment, to ergonomics. This is an area that is intrinsically valuable, but in which specialist knowledge is essential. It is probably sufficient in this course to demonstrate that some analytic apparatus does exist, and that it is capable of yielding important information. Moreover, because of the strict experimental approach such work is an excellent illustration of the extension of scientific enquiry into fields that go beyond the purely physical universe.

A course of this nature should give a student a sufficient equipment to think coherently about the problems of management as a decision-making process, but it may be difficult for him to relate the abstract notions to the real world. This approach is valuable, if only to prevent the student from believing he has been ' trained ' as a manager, but American experience in courses similarly biased toward ' management science ' has tended to suggest that the degree of abstraction easily becomes too great. The proposal on the Cambridge course is to associate a series of men holding operating management jobs with the teaching, bringing them in to lead discussion groups on their own special fields. In this setting it should be possible for the student to explore the relevance of the ideas and concepts that stem from the formal teaching to actual behaviour in current industrial situations. There will be problems, particularly of vocabulary, in these meetings, but to the extent that they are successful, they will do something to fill the gap between the course and the industrial world. They should also introduce the student to the general procedures and attitudes of the various functional fields of industry, marketing production, personnel administration, etc., which will be only lightly touched upon in the main teaching. In the same context each man will be required to complete an individual project which will normally be a report on field-work. the observation or investigation of a process in an industrial setting.

As a general point, teaching methods will be eclectic. The great contribution of the American business schools to the educational world has been an array of new techniques, such as case study, the incident process and many other non-directive, participant patterns that have several advantages over the traditional teacher-taught, jug-of-wisdom and sponge relationship, especially in areas where there is little deterministic content. It is intended that the first classes shall be kept small so that there may be experiments in technique as well as in content. The course is designed to encourage men. who have a basic scientific education, to believe that that approach has valuable extensions into the various fields of knowledge that underlie management and at the same time to demonstrate the limits of strictly quantitative analysis; if it is to be effective, its students must understand in addition to knowing, and such understanding is more easily achieved through involvement and participation.

Le Department of Engineering de l'Université de Cambridge organise un cours d'un an sur les Principes de Gestion Industrielle. L'accès au cours est réservé aux étudiants qui ont déjà acquis un grade universitaire dans une discipline scientifique.

L'enseignement ne constitue pas un apprentissage des fonctions de gestion, mais il doit apporter le fondement d'une analyse des problèmes industriels et des comportements. L'accent est mis sur le développement de modèles analytiques formels, et en particulier, sur les modèles à base statistique, mais aussi un effort considérable est fourni pour suggérer que des problèmes d'autres domaines, moins aisément quantifiables, peuvent être traités à condition de disposer de techniques efficaces.

Ein einjähriger Kurs über die Grundlagen industrieller Führung wurde in der Abteilung für Ingenieurkunde der Universität Cambridge eingerichtet. Die Teilnahme ist auf Studenten beschränkt, die eine Prüfung auf einem wissenschaftlichen Gebiet abgelegt haben.

Der Kurs beabsichtigt nicht, industrielle Leitung zu schulen, sondern den Grund für eine Analyse industrieller Probleme und Verhaltensweisen zu legen. Es wird dabei Wert auf die Entwicklung formaler analytischer Modelle gelegt, besonders solcher, die statistisch begründet sind. Daneben laufen Bemühungen, andere weniger leicht quantifizierbare Probleme mit geeigneten Methoden zu bearbeiten.

References

Cambridge University Reporter, 1959, **89**, No. 24, 18 Feb.

Festinger, L., 1950, Informal social communication. *Psychol. Rev.*, **57**, 271–282.

Forrester, J., 1958, Industrial dynamics. *Harvard Business Rev.*, **36**, No. 4, 37–66.

Homans, G. C., 1951, *The Human Group* (London : Routledge and Kegan Paul).

Newcomb, T. M., 1955, *Social Psychology* (London : Tavistock).

Simon, H. A., 1957, *Models of Man* (New York : Wiley).

Tustin, A., 1953, *The Mechanism of Economic Systems* (London : Heineman).

Zaleznik, A., 1958, *The Motivation, Productivity and Satisfaction of Workers* (Harvard University Division of Research).

THE INTERNATIONAL ERGONOMICS ASSOCIATION

In 1957 the European Productivity Agency organized an international Seminar on the subject of 'Fitting the job to the worker'. This was held at the Netherlands Institute of Preventive Medicine in Leyden and some 70 experts from ten European countries and the U.S.A. took part (see *Ergonomics*, **2**, 305).

Scientists from different disciplines, including physiology, anatomy and experimental psychology, discussed the application of biological sciences to the problems of human work and the optimal use of human abilities. The seminar urged the formation of a permanent international scientific body which would establish and maintain international contacts between scientists interested in this subject and nominated a Steering Committee which was charged with the task of preparing such an international organization.

The Committee nominated Professor G. C. E. Burger (Eindhoven, Holland) as its Chairman, Professor E. Grandjean (Zürich, Switzerland) as its Secretary and Professor K. U. Smith (Madison, Wisconsin, U.S.A.) as its Treasurer. The other members are Professor H. S. Belding (Pittsburgh, Pennsylvania, U.S.A.), Professor G. Lehmann (Dortmund, Germany), Professor N. P. V. Lundgren (Stockholm, Sweden), Dr. B. Metz (Strasbourg, France), Mr. R. G. Stansfield (London, England).

There are already international organizations dealing with some aspects of ergonomics or human engineering, but there is no such body specifically and exclusively taking care on an international basis of all the sciences which are involved. The Committee therefore came to the conclusion that the creation of an international body is highly desirable and necessary for the further development of this field of applied science.

The aims and objects of the organization now planned are the promotion and development of the biological sciences applied to human work on an international level, especially by facilitating contacts between scientists and by organizing international congresses and seminars. It is also intended to encourage the spread of this knowledge among physicians and engineers working in industry and among industrial management and employers' and workers' organizations. The organization is therefore designed to further two types of communication: between scientific disciplines and between science and industry, both on an international basis.

Experience has shown already that worker and production both generally profit from scientifically based working methods. The Association desires to found its activities on the objective scientific study of human activities and human reactions, free from any direct influence of an economic character, leaving the matter of application to those responsible for the conduct of industry.

The changing demands of modern industry, the increasing application of mechanization and automation and the concept of constructive medicine aiming not only at the prevention of disease and accidents, but also at the realization of health all focus attention on man as necessarily the central object of interest in the study of industrial performance.

LETTER TO THE EDITOR

Dear Sir,

The Vernon Prize

The late Dr. H. M. Vernon made a bequest to the National Institute of Industrial Psychology expressing the wish that the Institute should award a prize every second year to the investigator who, being a British subject and under the age of 45 years, has in the opinion of the Council of the Institute done the most valuable research work in service of industrial psychology or industrial physiology. The fourth award will be made in 1960; it will consist of approximately £40 in cash and a silver medal.

Recommendations are invited of the names of workers in this field whom the Council should consider. Direct applications for the award may also be made. Recommendations or applications, supported by reference to published work and, if possible, copies of unpublished but relevant reports, should be made to me at this address before the end of February, 1960.

National Institute of Industrial Psychology,
14 Welbeck Street,
London, W.1.

Yours faithfully,
G. Humphrey Smith,
Secretary.

SUMMARIES OF PAPERS PUBLISHED ELSEWHERE

Authors of papers of ergonomic interest which have been published in other journals or which are available as privately circulated reports are invited to submit summaries for publication in this Journal. They may be sent to any member of the Editorial Board and should be accompanied by a copy of the full paper which will be returned to the author on request.

McFarland, R. A., and Domey, R. G. (1958). Bio-technical aspects of driver safety and comfort. *Trans. Soc. automot. Engrs, N.Y.*, **66**, 630–648.

Some of the conditions considered to be impediments to efficient and safe operation of one or more of the ten different trucks studied may be summarized as follows :

1. Fixed limits of driver's cab. With few exceptions the driver's cab was considered to be too small for operators larger than the 65th percentile. For instance, if seats were adequately adjustable it would be impossible to place them most advantageously in most cabs because of space limitations or because of peculiarities of cab shape.

2. Physical dimensions of seats. In some instances the physical dimensions of seats did not meet certain minimum human sizing seating criteria, especially with respect to width and depth of the seat pan, and width and height of seat back.

3. Degree of adjustability of seats. There was not a single instance in which the adjustability available in either the vertical or horizontal plane met minimum criteria. In one vehicle a certain seat could not be adjusted in any direction. At least half the seats could not be vertically adjusted at all. In almost all those seats that could be adjusted in either plane, the range of adjustability was too small.

4. Human sizing accommodations. On almost every truck the placement, static dimensions, and degree and range of adjustability of seats clearly favoured the smaller driver. It was also discovered that some of the forward adjustability provided was wasted, since, when the seat was moved forward the space between the steering wheel and seat back became less than the abdomen depth of persons at the 75th percentile. Some improvements could have been made had the seat rack been mounted toward the rear of the cab. As pointed out above, this was usually impossible in view of cab structure.

5. Arrangement of dials and gauges on instrument panel. A very wide variation among vehicles was found in both the previous study published in 1953 and the present one as well. There is some evidence that dials and gauges have been placed nearer the operator. However, the variation found in the location, placement, size, degrees of visibility, presentation of information, and angle of instruments suggests that displays are not designed to follow any special pattern, nor to depend upon the system related to common human factors. Some gauges and dials were wholly or partly hidden behind other instruments mounted on the steering column. Often a certain gauge measuring

the same thing would be found to vary widely in design in different vehicles. The variation in tachometers would be a specific example.

6. Placement of levers, knobs, and pedals. At least 22 per cent of all hand controls found in 10 vehicles were considered to be located too far away from the operator. Others were placed in disadvantageous positions, such as one important lever which was almost invisible behind the steering column, and was difficult to reach as well. In certain vehicles some operators could not reach pedals without striking their thighs on the steering wheel or shift levers. Some controls impeded the operation of others, and some required excessive effort to operate. It was found that although a great deal of auxiliary equipment was included in some cabs, the additional space required had not been built into the cabs. Thus items of equipment were at times disadvantageously placed.

7. Design of visors, wind-shields, mirrors, and wind-shield wipers. The curvature of wind-shields varied, resulting in different degrees of distortion in vision. In some instances the wind-shield wipers did not fit the curvature of the windows they were supposed to clean. The size and quality of mirrors were highly variable, and in some instances the mountings were not adequate for preventing vibration. Visors often did not wholly shield the eyes from bright incident light, and there was considerable 'leakage' which was uncomfortable. Some vehicles had only a single visor.

8. Temperature, humidity, noise level, and CO concentration in cab. In some vehicles the noise level approaches the discomfort level. Small amounts of CO were found in some cabs, but no cab was considered to have dangerous concentrations. Because of the wide variety of environmental conditions under which the vehicles were studied, only preliminary measurements of temperature and humidity were attempted. In general, humidity levels were not excessive. Temperature was found to be slightly variable. This area of biotechnology in vehicles needs intensive development.

9. Implications of design variation and design standardization. A great many design features of vehicles have been 'standardized', for example, seal-beam headlights and standardized cabs that are interchangeable among different types of chassis. In passenger cars the size of the space provided for number plates, and the diameter of steering wheels vary only within a very narrow range; thus, there is no objection to standardization of design features in principle. The data from this study, however, show that a great many other design features of equal or more importance vary in dimension, size, location, and in many other ways without any discernible relationship to the variation of human factors they are supposed to accommodate. For instance, both within the same manufacturing concern and from one to another, seating arrangements were found to be highly variable. One manufacturing concern has one kind of truck in which the seating arrangements were identical and, therefore, 'standardized' for that line. In another line, the seating arrangements were standardized with different dimensions. Thus, each of the two types of trucks, would best accommodate only certain segments of the population of vehicle operators. Also, different manufacturers had seating arrangements which accommodate one segment of the operator population better than another.

It seems doubtful whether vehicle manufacturers have reliable standards available to ensure accommodating variations of human body size, or if such standards are available they have not been used to maximum advantage.

HARPER, R. (1958, 1959), Psychological aspects of laboratory work (Parts I–VII). *Lab. Practice*, **7,** 578–580, 648–651, 712–714; **8,** 17–20, 51–54, 87–90, 135–138.

This series of articles outlines a number of topics familiar to students of psychology which appear relevant to various aspects of laboratory work. Included in the first four parts are discussions of aptitude tests, their reliability and validity, of human factors involved in making instrumental measurements, of psychological methods and their application to laboratory practice. The last three parts are devoted to the reviewing of some recent observations about environmental conditions, of certain individual differences and their possible relevance to the selection and training of laboratory personnel and the assessment of individual and collective accomplishments in laboratory work.

SIMMONS, E. D. (1958), Operator training, a scheme and its results. *Engineering, Lond.*, June 13.

This article is based on five years' experience of specialized operator training methods at Guest and Nettlefolds (Midlands) Limited. The training was carried out under the aegis of the firm's training committee with the advice of an outside consultant.

Results were obtained in five manufacturing units and covered operations done by hand, by single-purpose machines, multi-purpose machines and by groups of machines controlled by one operator.

Details are given of improvements, following the introduction of the training schemes, in the length of learning time, labour turnover, ultimate level of operator performance, scrap returns and accident frequency. An account is also given of other benefits arising from improved operator training : new types of machinery were introduced smoothly : established operators were re-trained to a higher level of performance on their own or other jobs thus giving them higher earnings and greater versatility ; experienced workers were relieved of the responsibility of training newcomers and the right type of labour was attracted to the firm.

ERGONOMICS RESEARCH SOCIETY

PROCEEDINGS

A meeting held on 29th May, 1959 at the Building Research Station of the Department of Scientific and Industrial Research, Garston, Watford, Herts.

The following papers and demonstrations were presented:—

(1) " Climate and Thermal Discomfort in Equatorial Dwellings ", by C. G. Webb.

Equatorial building design is based on the exclusion of heat from the sun and the dispersal of metabolic and other heat arising inside the building. Dwellings may be classified according to the means of heat dispersal which is adopted: ventilation, storage in the fabric, or refrigeration. The typical equatorial house is designed for maximum ventilation. The diurnal variation of internal climate in 14 houses in Singapore was illustrated by records of the dry- and wet-bulb temperatures, relative humidity, the square root of the air velocity and by the temperature difference between globe and air thermometers (found to be quite small). Simultaneous assessments of thermal comfort by 18 fully acclimatized observers yielded a multiple regression equation, on which a new climatic index was based—the Singapore Index—correlating well ($r=0{\cdot}65\pm0{\cdot}027$) with thermal comfort. No other available index gave r greater than $+0{\cdot}55$ for the same data.

The incidence of discomfort due to warmth was analysed by the probit method, as was that due to cold. Probit regression lines were shown, and a fairly complete comfort graph with certain distinctive features:

(1) a high optimum at 78·7°F on the Singapore Index scale,

(2) a low maximum percentage of persons comfortable, 68 per cent at 78·7°F,

(3) a sharp maximum, e.g. a departure of 1°F from the optimum produced discomfort in 3 per cent of subjects,

(4) symmetrical points of inflexion and an asymptotic approach to zero of the complete comfort graph.

The low maximum in (2) indicates that a single climate is always likely to be unsatisfactory for subjects fully acclimatized to low latitudes since it fails to provide for individual thermal requirements. A spread of climate is necessary for this purpose, and the extent and effects of climatic spread in a room were described.

(2) " Vibration and its Effects ", by R. J. Steffens.

There are many aspects of structural vibration, one of the most important and interesting being the question of human sensitivity—the effect of vibration on people. Many complaints of vibration have arisen primarily because of this, and it is not generally appreciated what small vibratory movements can be detected.

Some fifty years ago when the first underground railway system came into being in London, it became necessary to carry out a vibration survey because of complaints. It was found that the main vibration frequency was 10–15 cycles per second (c.p.s.). At this frequency, an amplitude (vibratory movement) of one thousandth of an inch was noticeable, and if the amplitude was five times as great then some degree of annoyance was caused. This early investigation showed that people were sensitive to fairly small movements, but the sensation does not depend merely on amplitude but on a combination of amplitude and frequency. A greater amplitude can be tolerated at low frequencies (of the order of 5 c.p.s.) than at high frequencies (of the order of 50 c.p.s.). The range 5–50 c.p.s. covers most structural vibrations—particularly from machinery.

The major contribution to knowledge on human sensitivity was made by German investigators just prior to the late war. Selected people were subjected either to vertical or to horizontal vibration on a special platform and were asked to state their reactions to known vibrations. It was possible to define zones of sensitivity, the zones allowing for individual variations in assessment although this was less than might be expected. People are most sensitive to vertical vibration when standing up, but detect horizontal vibration best when they lie down. At 50 c.p.s. it is quite possible to detect amplitudes as small as a tenth of a thousandth of an inch, at 10 c.p.s. an amplitude of about one hundredth of an inch would be considered unpleasant. Various units of intensity of vibration have been proposed, the most useful of which is the vibrar unit. This can be used to give a scale analogous to the standard loudness scale.

Other aspects of vibration are the effect on laboratory work, which is becoming very important today, the possibility of damage and methods of reduction. In connection with

the last, it is very often possible to reduce vibration by special mounting of machinery and the human sensitivity scales can help here. If a given vibration is causing annoyance for instance, one can determine by how much it should be reduced in order for the vibration to be more acceptable.

(3) " Washing Facilities in Public Buildings ", by J. H. Madge

This is one of the items in the programme of the Division of the Building Research Station which is concerned with the suitability of completed buildings with particular reference to the needs of users. This work entails collaboration between physicists, architects and engineers and human scientists (psychologists, sociologists and anthropologists) and one or more of each of these, together with a housing manager and a domestic scientist, are included in the staff of the Division.

The methods used include the study of documents (e.g. the study of coroner's records to ascertain the causes of fatal domestic accidents), observation methods (e.g. the study of the housewife's movements in a ' mock-up ' home, and activity sampling in drawing offices), interviews and questionnaires ranging from test questions (e.g. for scalogram analysis) through normal mass interviews (used in a great variety of cases to ascertain the experiences and attitudes of selected informants) to non-directive depth interviews (used in special studies of adaptation to a new housing estate). Linked with all these are physical measurements, for example, of temperature, humidity, sound levels, lighting and of spatial dimensions.

The history of the spray tap development began in 1949 when the Treasury Medical Adviser advocated running water for ablutions on grounds of hygiene. Some spray taps were installed in a Government Office, and a questionnaire on various aspects of washing facilities was circulated to users. The answers showed a generally favourable attitude of users towards spray taps, except that the provision of one normally equipped basin was desired, for face washing and other special purposes, and objection was taken to the user's inability to control temperatures.

Shortly afterwards, in 1952, the Division (now transferred to the Building Research Station from the Ministry of Works) received a request to undertake a more extended study of the suitability of spray taps. The general questions were whether a spray tap installation was more economical than a normal installation and whether it was at least equally acceptable to users. In order to answer these questions a large Government Office was chosen for study. The first point was how many people habitually used each lavatory in the block. This was answered by means of a questionnaire showing a digrammatic picture of the block on which the lavatory normally used could be marked. The results provided the basis of calculations of the number of office workers using each basin and W.C. How much water was used in each lavatory for each purpose was ascertained by installing a total of 70 meters in the hot and cold water supply pipes throughout the building, and by making a small subsidiary inquiry to discover how much basin water was used for office cleaning purposes.

The third item was the actual use of basins. For this purpose two lavatories (M. & F.) were set up with a spray tap installation in each all basins except one, being fitted with a spray tap. These two lavatories, together with two normal lavatories (also M. & F.), were instrumented, using unobtrusive contacts on each tap which were wired back to multiple pen recorders to mark every occasion that a tap was turned on. The fourth question was the extent to which users voluntarily chose spray tap basins in preference to normal basins. These and other facts were obtained by spot observations. Finally the question of satisfaction was examined by an interview survey.

The results showed spray taps to be acceptable to both men and women, 50 per cent of men and 70 per cent of women expressing a preference for washing by sprays. Sprays were often in use when the normal basin was free, but the provision of a normal basin was appreciated for purposes other than hand wash. The use of spray taps was shown to save at least one-half of the water supply, considerably more of hot water than of cold.

The main objection to spray taps was again that temperatures could not be controlled by users. As a result of this, steps have been taken to develop a mixing spray tap in which the temperature is under the control of the user. This tap delivers water at an even further reduced rate, so much so that the avoidance of ' dead-legs ' from the hot water supply becomes of major importance. A further consequence has, therefore, been the development of an installation based on a small local electric water storage heater.

(4) " Use of Film Techniques at the Building Research Station ", by J. Rogers.

The films used by three previous speakers to illustrate their talks provided examples of three important applications of the film at the Building Research Station; as a research tool, as a means of recording, and as a medium for giving technical information. While all these applications were important, the first two had priority over the third in the work of the Film Section; an attempt was made to give an ' on demand ' service to scientific staff wishing

to use the film for research and record purposes, and only after such demands had been met was it possible to devote time to making technical information films.

As a research tool, the film had many applications, of which perhaps the best known was high-speed photography whereby extremely rapid motion could be slowed down sufficiently to be rendered visible. Use was sometimes made of this technique but not very often. There was rather more interest in time-lapse photography, by which very slow movement could be made visible: at present this technique is being used to study rain penetration through a wall.

More often, however, filming is carried out at the normal speed of 24 frames/sec. This permits the study of all kinds of movements that take place at moderate speeds; the flow of smoke from chimneys, the movement of air in a building (made visible by meta-fuel tracers), the flow of water discharged from basins and W.C.s, and the movements of people. Dr. Harper's work on flooring research provided an interesting example of the latter; here the film made it possible to measure the area of contact between foot and floor and provided information that could not otherwise have been obtained.

Straightforward record films are widely used; here no attempt is made to measure anything, but simply to record what happens. This is particularly useful when carrying out experiments that are difficult and costly to repeat; by viewing the film record the experiment can be re-witnessed again and again, by the scientific staff concerned, until all the desired information has been obtained from it and agreement reached on its interpretation. Small points are sometimes revealed that escaped observation in the course of the experiment because attention was concentrated on its major aspects. Such film records are sometimes of value for showing to committees or at meetings of professional bodies when they will often carry greater conviction than a printed report or a lecture. Used in this way, they become the simplest kind of *technical information film*—a record film suitably edited and titled, usually with a live commentary given by the lecturer.

When it is desired to give very wide publicity to the results of research, a sound film is made. This involves a much greater expenditure of staff time than the films previously mentioned; but such a film will stand alone and can be widely circulated. The Station now has 18 technical information films which are available on free loan from the Ministry of Works: between them they average about 900 showings a year.

Films and printed publications are complementary media of information; the film could arouse interest and carry conviction better than the printed word but could rarely give sufficient details to enable a new idea to be put into practice: moreover, its message could easily be forgotten. Our films are, therefore, associated with printed publications where possible and reference was usually made to these at the end of the films.

Part of a film record of working conditions in a drawing office, was shown with a commentary on magnetic tape.

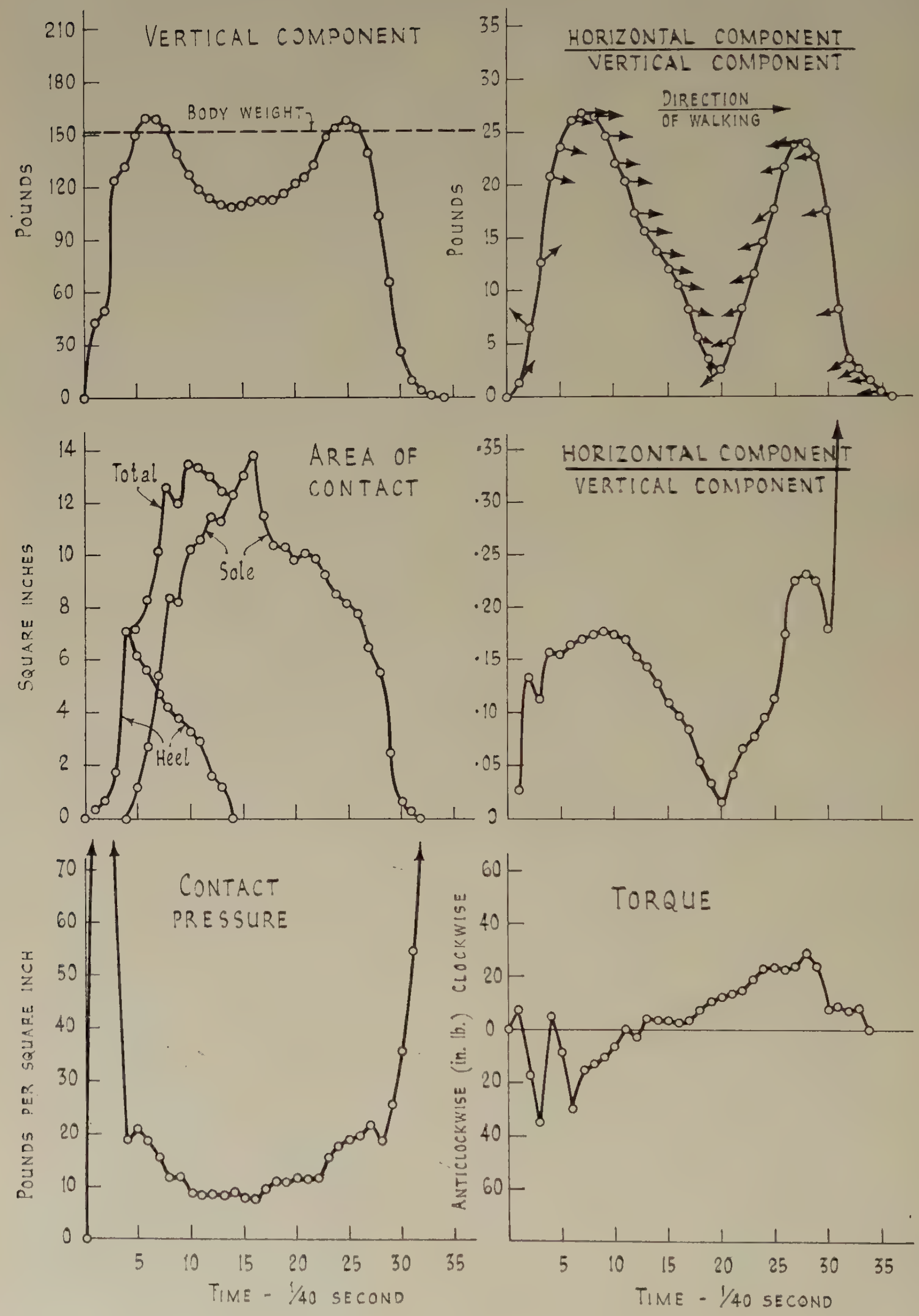
(5) " Flooring section ", by F. C. Harper.

The work of the flooring section on the mechanics of walking was shown by film and demonstration. The purpose of this work is to provide data for the construction of a rational accelerated abrasion machine and also to provide insight to the problem of slipperiness.

The subject of the experiment steps first on to a ' force plate ' then with the next step of the same foot on to a glass plate. The force plate, a modification of that described by D. O. Cunningham and G. W. Brown (*Proc. Soc. exp. Stress Analysis*, 1952, **9,** 2), is used in conjunction with a dynamic strain recorder to indicate the changing pattern with time of the three components of the force applied, the torque and the coordinates with respect to the plate, of the centre of pressure. The glass plate, but so that the area of contact of the foot is dark, is photographed through a mirror at 40 frames/sec to provide a record of changing area with time. The records of the two steps are related to provide pressure/time relationship.

The work has been developed for many subjects walking straight, round corners and up and down stairs. Fewer subjects have been used for walking up and down ramps and carrying loads.

A typical series of results for a person walking straight is shown in the figure (p. 408): the ratio of the horizontal to vertical component of the force allows a safe limit to be placed on the coefficient of friction between shoe and floor.


VERTICAL COMPONENT
BODY WEIGHT
POUNDS
HORIZONTAL COMPONENT / VERTICAL COMPONENT
DIRECTION OF WALKING
POUNDS
AREA OF CONTACT
Total
Sole
Heel
SQUARE INCHES
HORIZONTAL COMPONENT / VERTICAL COMPONENT
CONTACT PRESSURE
POUNDS PER SQUARE INCH
TIME - 1/40 SECOND
TORQUE
ANTICLOCKWISE (in. lb.) CLOCKWISE
TIME - 1/40 SECOND

INDEX OF AUTHORS

WITH THE TITLES OF PAPERS

PAGE

Abstracts of papers delivered at symposium on training, Bristol, 13–16 April 1958 223
Adamson, G. T. : Circuit training. 183

Bartlett, Sir Frederic : Some problems of scientific thinking . . . 229
Blain, Isabel : Practice and knack : some comments on learning and training in industry 167
Bonjer, F. H. : The effects of aptitude, fitness, physical working capacity, skill and motivation on the amount and quality of work . . . 254
Book Reviews:
The Church and Industry 313
Hilf, H. H. : Arbeitswissenschaft 313
Hill, J. M. M. : The time-span of discretion in job analysis . . . 311
McCormick, E. J. : Human engineering 311
Union of International Associations : Yearbook of International Organizations 312
Brown, J. R., Crowden, G. P. and Taylor, P. F. : Circulatory responses to change from recumbent to erect posture as an index of heat stress. . 262

Chambers, J. B., with Stockbridge, H. C. W. : Sighting with aided and unaided vision 386
Chiles, W. Dean : Effects of elevated temperatures on performance of a complex mental task 89
Coiley, Patricia A., with Davis, D. Russell : Accident-proneness in motor-vehicle drivers 239
Colquhoun, W. P. : The effect of a short rest-pause on inspection efficiency . 367
Cotes, J. E. and Meade, F. : Physical training in relation to the energy expenditure of walking and to factors controlling respiration during exercise 195
Crossman, E. R. F. W. : A theory of the acquisition of speed-skill . . 153
Crowden, G. P., with Brown, J. R. and Taylor, P. F. : Circulatory responses to change from recumbent to erect posture as an index of heat stress . 262

Davis, D. Russell : Human errors and transport accidents 24
Davis, D. Russell and Coiley, Patricia A. : Accident-proneness in motor-vehicle drivers 239
Department of Scientific and Industrial Research : Ergonomics Sub-committee of the Human Sciences Committee 310

Editorial Note 114
E.P.A. Project No. 335 : "Fitting the job to the worker" 305
Ergonomics Research Society :
Advance Notice of Tenth Annual Conference 118
Advance Notice of Eleventh Annual Conference 320
Annual General Meeting 315
List of Members 118
Proceedings 114, 317, 405

PAGE

Floyd, W. F. and Roberts, D. F.: Anatomical and physiological principles in chair and table design 1

Garvey, W. D., with Taylor, F. V.: The limitations of a 'procrustean' approach to the optimization of man–machine systems. 187
Gerhard, D. J.: The judgment of velocity and prediction of motion . . 287
Griew, Stephen.: A study of accidents in relation to occupation and age . 17
Grimaldi, John V.: Sensori-motor performance under varying noise conditions 34

Heinonen, A. O., Karvonen, M. J. and Ruosteenoja, R.: Energy expenditure of walking on snow at various depths 389
Hemingway, Albert: Physiological bases of training 133
Henderson, J. G.: The estimation of the transfer function of a human operator by a correlation method of analysis 274
Hopkinson, R. G. and Longmore, J.: Attention and distraction in the lighting of working-places 321

International Ergonomics Association 400

Jackson, K. F.: Behaviour in controlling a combination of systems . . 52
Jackson, K. F.: Behaviour in controlling a combination of systems. II. Effects of changes in the velocity of disturbances 363

Karvonen, M. J.: Problems of training of the cardiovascular system . . 207
Karvonen, M. J. with Heinonen, A. O. and Ruosteenoja, R.: Energy expenditure of walking on snow at various depths 389
King, S. David M.: The operator as a self-regulating system: a factory experiment 171
Kurke, Martin I.: Personnel variables in the analysis of man–machine systems 349

Leonard, J. Alfred.: The effects of 'machine' lag on a serial choice task with balanced and biased input frequencies 44
Letters to the Editor 108, 401
Longmore, J., with Hopkinson, R. G.: Attention and distraction in the lighting of working-places 321
Loveless, N. E.: The effect of the relative position of control and display upon their direction-of-motion relationship 381

Meade, F., with Cotes, J. E.: Physical training in relation to the energy expenditure of walking and to factors controlling respiration during exercise 195
Müller, E. A.: Training muscle strength 216

Pepler, R. D.: Warmth and performance: an investigation in the tropics . 63
Provins, K. A.: Environmental conditions and driving efficiency: a review. 97

Roberts, D. F., with Floyd, W. F.: Anatomical and physiological principles in chair and table design 1
Rosenberg, Seymour: A laboratory approach to interpersonal aspects of team performance 335
Ruosteenoja, R., with Heinonen, A. O. and Karvonen, M. J.: Energy expenditure of walking on snow at various depths 389

PAGE

Saul, Ezra V. : Note on current trends in literature on training . . . 180
Seymour, W. D. : Training operatives in industry 143
Shackel, B. : A note on panel layout for numbers of identical items . . 247
Singleton, W. T. : The training of shoe-machinists 148
Stockbridge, H. C. W. and Chambers, J. B. : Sighting with aided and unaided vision 386
Summaries of Papers Published elsewhere 110, 402

Taylor, F. V. and Garvey, W. D. : The limitations of a ‘ procrustean ’ approach to the optimization of man–machine systems 187
Taylor, P. F., with Brown, J. R. and Crowden, G. P. : Circulatory responses to changes from recumbent to erect posture as an index of heat stress . 262

Wilkinson, R. T. : Rest pauses in a task affected by lack of sleep . . . 373
Willett, F. J. : A new approach to teaching industrial management . . 394
Wilson, P. H. St. J. : Introductory address to symposium on training . . 125
Wolff, H. S. : Modern techniques for time and motion study in physiological research 354

INSTRUCTIONS TO CONTRIBUTORS

1. Articles for publication should be sent to the General Editor or to any Member of the Editorial Board.

2. Papers must be in English, French or German. Every paper must be accompanied by a brief summary, and contributors are asked if possible to supply summaries in all three languages.

3. Authors should submit a typescript, double-spaced on one side of the paper only. Footnotes should be avoided. Summaries, tables and legends for diagrams should be typed on separate sheets. Authors must ensure that the lay-out of mathematical and other formulae is clear. The typescript must represent the final form in which the author wishes the article to appear. The cost of any alteration in proof other than printers' errors may be charged to the author.

4. Diagrams should be drawn in black ink on white card or tracing paper. They should normally be sufficiently large to allow reduction in printing and the lines should therefore be bold. **All lettering should be up to draughtsmanship standard, suitably drawn in Indian ink to allow for reduction in size.** No charges are made for reproducing tables, diagrams or half-tone illustrations, but diagrams not suitable for reproduction without redrawing may be redrawn at the Author's expense.

5. References in the text should be indicated by author's name followed by the date. They should be listed alphabetically at the end of the paper in the style illustrated by the following examples:

BARTLETT, F. C., 1943, Fatigue following highly skilled work. *Proc. roy. Soc.* B, **131**, 247–254.

BEDFORD, T., 1948, *Basic Principles of Ventilation and Heating* (London: H. K. Lewis).

LE GROS CLARK, W. E., 1954, The anatomy of work. In *Symposium on Human Factors in Equipment Design* (Edited by W. F. Floyd and A. T. Welford) (London: H. K. Lewis). Pp. 5–15.

Abbreviations should be as in the *World List of Scientific Periodicals*.

6. **Consideration for publication will gladly be given to papers which have previously had a limited circulation as research reports.** Submission of a paper implies, however, that it has not been published and will not be published elsewhere without the permission of the General Editor and the Publishers. Copyright in material accepted for publication is retained by the Journal, and reproduction in whole or in part is forbidden except under the terms of the *Fair Copying Declaration* of the Royal Society or with the written permission of the Publishers.

7. Authors will receive 25 copies of their contributions without charge. Additional copies may be ordered at the time of returning proofs. Prices for additional copies may be obtained from the Publishers.

ERGONOMICS

Volume 2 August 1959 Number 4

Contents

Page

Attention and Distraction in the Lighting of Work-places. By R. G. Hopkinson and J. Longmore 321

A Laboratory Approach to Interpersonal Aspects of Team Performance. By Seymour Rosenberg 335

Personnel Variables in the Analysis of Man–Machine Systems. By Martin I. Kurke 349

Modern Techniques for Time and Motion Study in Physiological Research. By H. S. Wolff 354

Behaviour in Controlling a Combination of Systems. II. Effects of Changes in the Velocity of Disturbances. By K. F. Jackson 363

The Effect of a Short Rest-pause on Inspection Efficiency. By W. P. Colquhoun 367

Rest Pauses in a Task Affected by Lack of Sleep. By R. T. Wilkinson 373

The Effect of the Relative Position of Control and Display upon their Direction-of-motion Relationship. By N. E. Loveless 381

Sighting with Aided and Unaided Vision. By H. C. W. Stockbridge and J. B. Chambers 386

The Energy Expenditure of Walking on Snow at Various Depths. By A. O. Heinonen, M. J. Karvonen and R. Ruosteenoja 389

A New Approach to Teaching Industrial Management. By F. J. Willett ... 395

The International Ergonomics Association 400

Letter to the Editor 401

Summaries of Papers Published Elsewhere:
(i) McFarland, R. A. and Domey, R. G. 402
(ii) Harper, R. 404
(iii) Simmons, E. D. 404

Ergonomics Research Society:
Proceedings 405

Index of Authors (with the Titles of Papers) 409